EVALUATION OF PULVERISED STRANDS OF *CISSUS POPULNEA* AS BINDER FOR PRODUCTION OF FOUNDRY CORES

BY

Fidelis Mfewase ACHIV; B.ENG (MET.), M.Sc (MET)
Ph.D/ENG/01885/2006 - 07

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

AUGUST, 2011

EVALUATION OF PULVERISED STRANDS OF *CISSUS POPULNEA* AS BINDER FOR PRODUCTION OF FOUNDRY CORES

BY

Fidelis Mfewase ACHIV; B.ENG (MET.), M.Sc (MET)

Ph.D/ENG/01885/2006 - 07

A DISSERTATION SUBMITTED TO THE POSTGRADUATE SCHOOL AHMADU BELLO UNIVERSITY, ZARIA NIGERIA

IN PARTIAL FULFILMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN METALLURGICAL AND MATERIALS ENGINEERING

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

AUGUST, 2011

DECLARATION

I declare that the work in this dissertation entitled "Evaluation of Pulverised Strands of *Cissus populnea* as a Binder for the Production of Foundry Cores" has been performed by me in the Department of Metallurgical and Materials Engineering under the supervision of Dr. O. Aponbiede. The information derived from the literature has been duly acknowledged in the text and a list of references provided. This dissertation has not been presented for another degree or diploma at any University previously.

Name of Student	**Signature**	**Date**

CERTIFICATION

This dissertation entitled "Evaluation of Pulverised Strands of *Cissus populnea* as a Binder for the Production of Foundry Cores" meets the regulations governing the award of Doctor of Philosophy – Metallurgical and Materials Engineering Department of Ahmadu Bello University, Zaria – Nigeria, and is approved for its contribution to knowledge and literary presentation

_____	_____	_____
Chairman, Supervisory Committee Dr O. Aponbiede	Signature	Date
_____	_____	_____
Member, Supervisory Committee Professor S. B. Hassan	Signature	Date
_____	_____	_____
Member, Supervisory Committee Professor S. A. Yaro	Signature	Date
_____	_____	_____
Head of Department Dr. O. Aponbiede	Signature	Date
_____	_____	_____
Dean, Postgraduate School Professor A. A. Joshua	Signature	Date

DEDICATION

This work is dedicated to my late Parents Mr. Isaac Achiv Ager and Mrs. Adoo Achiv.

ACKNOWLEDGEMENT

I thank Almighty God for his mercy and guidance over my life and for providing me with the requisite knowledge to undergo this programme. I wish to specifically acknowledge the contributions of my major supervisor Dr. Ola Aponbiede who monitored and painstakingly contributed and advised at every stage of this work. His support has immensely contributed to the success of this work.

I also thank the other members of the supervisory team: Prof. S.B. Hassan and Prof. S.A. Yaro. Their moral support and advice also contributed to the level of success attained in this work.

To my late parents, I appreciate all they did including the sacrifice they made to give me a sound education.

I am also indeed very grateful to my wife, Mrs B.M. Achiv and all the other members of my family for the understanding they have shown during the course of this research.

I am grateful to Mr. Danladi Adamu, the Technologist attached to the Metallurgical laboratory and indeed all the members of staff of the Department of Metallurgical and materials Engineering, Ahmadu Bello University, Zaria.

I must not forget to appreciate Engr. L.A. Isah and Dr F.A.Tiseer for their valuable contributions, Engr. S.O. Jolaiya Executive Director, Centre for Automotive Design and Development A.B.U; Zaria, Mr Dogara Jattau and my other numerous colleagues at the Centre, Engr. Aminu Jalal, Director General, National Automotive Design and Development Council for their moral support and encouragement May Almighty God reward you all in Jesus name.

ABSTRACT

Core binding properties of pulverised strands of *cissus populnea* plant were evaluated with the view to adding to the list of core binders available locally. The strands of *cissus populnea* were extracted from the stem of the plant, dried and milled to obtain a fine powder that was sieved using sieve aperture of +200. Chemical analysis of the pulverised strands showed that it had 6.1% fatty acids (lipids). Further analysis of the lipids showed that the pulverised strands had 61.76% Freidelan-3-one by weight of the lipids. Cores were produced using this powder as binder. The cores were baked at temperatures of 160, 180 and 200^0C for a period of 1 to 2hours respectively. Baking time was varied at 30 minutes intervals. The maximum baked tensile strength of 1380KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs and baking temperature of 160^0C. A mathematical model was used to ascertain the reliability of the experimental data. This model produced a coefficient of +0.99 which quite confirms the reliability of the process. Trial casting of grey cast iron were made utilizing cores made with above composition while a mix containing 5% binder, 7% water, 0.5% cassava starch and 87.5% sand, baking time of 1.5hours and baking temperature of 160^0C was used to make moulds and cores for the casting of aluminium alloys. The shake out as well as collapsibility of the mould and cores was good. This suggests that cores made using this binder are suitable for casting of both ferrous and non ferrous metals.

TABLE OF CONTENTS

Title Page		ii
Declaration		iii
Certification		iv
Dedication		v
Acknowledgement		vi
Abstract		vii
Table of Contents		viii
List of Figures		xiii
List of Tables		xx
List of Plates		xxiii
List of Appendix		xxv
Abbreviations, Symbols and Notations		xxvi
CHAPTER 1:	**INTRODUCTION**	
1.1	Background……..	1
1.1.1	Application of Cores…….	1
1.2	Statement of Research Problem……	3
1.3	Justification for the Study…….	4
1.4	Objectives of this Research……	5
CHAPTER 2:	**LITERATURE REVIEW**	
2.1 Cores……		6

2.1.1 Core Binder…….. 7

2.1.2 Core Sand……. 9

2.1.2.1 Sieve analysis of foundry sands…… 10

2.1.2.2 Physical Properties of Spent Foundry Sand…… 10

2.1.2.3 Chemical Properties of Spent Foundry sand…… 12

2.1.2.4 Mechanical Properties of Spent Foundry Sand… 14

2.1.3 Ceramic Aggregate……. 18

2.2 Classification of Core Binders…… 18

2.2.1 Limitations of Core Binders in use…… 19

2.2.1.1 Sodium Silicate/CO_2 Process…….. 19

2.2.1.2 Starch ……... 21

2.2.1.3 Oils……. 23

2.2.1.4 Molasses…… 27

2.2.1.5 Linseed Oil……. 27

2.2.1.6 Synthetic Resins……. 29

2.2.1.7 Other Recent Indigenous Findings on Core Binders… 29

2.3.0 Drying of Cores……. 30

2.4.0 No Bake binders……... 31

2.4.1 Furan Binders……... 31

2.4.2 Phenolic Urethane……. 32

2.4.3 Ester Cured Phenolic……. 33

2.4.4 New Developments in No bake Binders…….. 33

2.4.4.1 New Furan Technology……. 34

2.4.4.2 Protein Based binders…… 35

2.5 Characteristics of Cores used in Producing Aluminium castings……. 36

2.6 Casting Defects Associated with Core Binders……. 37

2.6.1 Surface and Sub Surface gas Defects…….. 38

2.6.2 Permeability of Cores……. 41

2.6.2.1 Effect of Core Age…… 44

2.6.2.2 Effect of Sand Permeability……. 44

2.6.2.3 Effect of Measurement…….. 45

2.6.3 Permeability Limitations……. 45

2.6.4 Porosity Defects…….. 46

2.7 *Cissus populnea*…… 52

2.8 Core Production……. 55

2.9 Mechanical properties of foundry sand cores……. 56

2.10 Mechanism f Bonding……. 59

CHAPTER 3: EXPERITMENTAL PROCEDURE

3.1 Materials…… 61

3.2 Equipment…… 61

3.3 Proximate Analysis of *Cissus populnea*…… 61

3.4 Methodology…… 62

3.5 Development of a statistical model for core binding process…. 65

3.5.1 Model for prediction of baked tensile strength of cores……. 66

CHAPTER 4: RESULTS

4.1 Sieve analysis and chemical composition of bacita sand……. 68

4.2 Baked tensile strength values of core samples……. 68

4.3 Other tested parameters of core samples containing 7% *cissus populnea* as binder……. 68

4.4 Chemical composition of *cissus populnea* and its lipids (fatty acids)….. 68

4.5 Graphs of physical parameters of core samples…….. 68

4.6 Statistical model for predicting baked strength of core samples…. 69

4.7 Samples of cast materials whose cores are made of 5% and 7% *cissus populnea*…… 69

4.8 Comparism of baked tensile strength of 7% *cissus populnea* with other values developed using other local binders by other researchers…….. 70

CHAPTER 5: DISCUSSION OF RESULTS

5.1 Composition and grain fineness number of bacita sand…… 120

5.2 Effect of *cissus populnea* on the development of baked tensile strength… 120

5.3 Effect of water content on the development of baked tensile strength… 126

5.4 Effect of baking time on developing baked tensile strength…….. 127

5.5 Effect of baking temperature on developing baked tensile strength….. 129

5.6 Permeability…….. 129

5.7 Statistical design and developed mathematical model for *cissus populnea*.. 130

5.7.1. Model for prediction of baked tensile strength……. 130

5.8 Trial castings…… 133

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion…… 135

6.1.1 Contribution to knowledge…… 136

6.2 Recommendation…… 137

REFERENCES……. 138

APPENDICES……. 145

LIST OF FIGURES

FIGURE

2.1 Expansion characteristics of different types of sand…… 17

4.1 Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch with water content of 4, 5 and 6% at baked temperature of 160^0C for baking time of 1 -2 hours..... 71

4.2 Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch with water content of 4, 5 and 6% at baked temperature of 180^0C for baking time of 1 -2 hours…… 72

4.3 Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch with water content of 4, 5 and 6% at baked temperature of 200^0C for baking time of 1 -2 hours…… 73

4.4 Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4, 5 and 6% at baked temperature of 160^0C for baking time of 1 -2 hours…… 74

4.5 Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4, 5,6 and 7% at baked temperature of 180^0C for baking time of 1 -2 hours…… 75

4.6 Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6 and 7% at baked temperature of 200^0C for baking time of 1 -2 hours…… 76

4.7 Effect of baked strength property of 5% *cissus populnea* and

0.5% cassava starch with water content of 4, 5,6,7 and 8% at baked temperature of 160^0C for baking time of 1 -2 hours…… 77

4.8 Effect of baked strength property of 5% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7, and 8% at baked temperature of 180^0C for baking time of 1 -2hours…… 78

4.9 Effect of baked strength property of 5% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7, and 8% at baked temperature of 200^0C for baking time of 1 -2 hours…….. 79

4.10 Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 160^0C for baking time of 1 -2 hours…… 80

4.11 Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 180^0C for baking time of 1 -2 hours…….. 81

4.12 Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 200^0C for baking time of 1 -2 hours…… 82

4.13 Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 7, 6 and 8% at

baked temperature of 160^0C for baking time of 1
-2 hours…….. 83

4.14 Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 180^0C for baking time of 1-2 hours…….. 84

4.15 Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 200^0C for baking time of 1-2 hours…… 85

4.16 Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content…… 86

4.17 Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content…….. 87

4.18 Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content…….. 88

4.19 Effect of baked strength property of 4% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content…… 89

4.20 Effect of baked strength property of 4% *cissus populnea* and

0.5% Cassava starch at baked temperature of 180^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 7% water content…… 90

4.21 Effect of baked strength property of 4% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 7% water content…… 91

4.22 Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 92

4.23 Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^{0}C, baking time of 1, 1.5 and 2 hours at 4 –8% water content…… 93

4.24 Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 94

4.25 Effect of baked strength property of 6% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 95

4.26 Effect of baked strength property of 6% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^{0}C, baking time of 1, 1.5 and 2 hours at 4 –8% water content…… 96

4.27 Effect of baked strength property of 6% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^{0}C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 97

4.28 Effect of baked strength property of 7% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 98

4.29 Effect of baked strength property of 7% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 –8% water content…… 99

4.30 Effect of baked strength property of 7% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content…… 100

4.31 Effect of baked strength property of 3 - 7% *cissus populnea,* 0.5% cassava starch, 4% water baked at a temperature of 160^0C, baking time of 1 - 2 hours…….. 101

4.32 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 4% water baked at a temperature of 180^0C, baking time of 1 - 2 hours…… 102

4.33 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 4% water baked at a temperature of 200^0C, baking time of 1 - 2 hours…… 103

4.34 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 160^0C, baking time of 1 - 2 hours…… 104

4.35 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 180^0C,

baking time of 1 - 2 hours…… 105

4.36 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 200^0C, baking time of 1 - 2 hours…… 106

4.37 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 160^0C, baking time of 1 - 2 hours…… 107

4.38 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 180^0C, baking time of 1 - 2 hours…… 108

4.39 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 200^0C, baking time of 1 - 2 hours…… 109

4.40 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 160^0C, baking time of 1 - 2 hours…… 110

4.41 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 180^0C, baking time of 1 - 2 hours…….. 111

4.42 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 200^0C, baking time of 1 - 2 hours…… 112

4.43 Effect of baked strength property of 3 - 7% *cissus populnea*,

0.5% cassava starch, 8% water baked at a temperature of 160^0C, baking time of 1 - 2 hours…… 113

4.44 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 8% water baked at a temperature of 180^0C, baking time of 1 - 2 hours…… 114

4.45 Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 8% water baked at a temperature of 200^0C, baking time of 1 - 2 hours…… 115

4.46 Optimum baked strength property developed at 7% *cissus populnea* , 0.5% cassava starch baked at a temperature of 160, 180 and 200^0C, baking time of 1 - 2 hours…… 116

5.1 Actual values with predicted values…….. 133

LIST OF TABLES

TABLE

2.1 Typical physical properties of spent foundry sand from green sand…… 11

2.2 Chemical composition of a typical sample of spent foundry sand as determined by x-ray fluorescence…….. 13

2.3 Mechanical properties of spent foundry sand…….. 14

2.4 Advantages and disadvantages of inorganic binders……. 19

2.5 Properties of fats and oils and their iodine values……. 26

2.6 Accepted Mechanical Property ranges of foundry sand cores…….. 57

2.7 Baked tensile strength of foundry sand cores……. 58

2.8 Classes of Iron/Steel castings by weight……. 58

3.1 Test - Factors for developing core strength…… 65

3.2 Factorial Design of *cissus populnea* as binder for core production showing the combinations of chosen factors…… 66

5.1 Complete matrix including interactions with effects calculated……. 130

5.2 Analysis of variance to identify factors influencing baked tensile strength of cores…….. 130

5.3 Comparison of the Actual baked tensile strength with the predicted values……. 132

A1 Chemical analysis of Bacita foundry sand…… 145

A2 Sieve analysis of Bacita foundry sand……. 146

B1 Strength in KN/m^2 of 3% *Cissus populnea* 0.5% cassava starch bonded

cores with varying water content baked at 160^{o}C….. 147

B2 Strength in KN/m^{2} of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C…… 147

B3 Strength in KN/m^{2} of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C….. 147

B4 Strength in KN/m^{2} of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C….. 148

B5 Strength in KN/m^{2} of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C…. 148

B6 Strength in KN/m^{2} of 3% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C….. 149

B7 Strength in KN/m^{2} of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C…… 149

B8 Strength in KN/m^{2} of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C…… 149

B9 Strength in KN/m^{2} of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C…… 150

B10 Strength in KN/m^{2} of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C…… 150

B11 Strength in KN/m^{2} of 3% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C…… 151

B12 Strength in KN/m^{2} of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C…… 151

B13 Strength in KN/m^2 of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^oC…… 151

B14 Strength in KN/m^2 of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^oC….. 152

B15 Strength in KN/m^2 of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^oC….. 152

C1 Properties of cores made with 7% binder, 7% water, 0.5% cassava starch and 85.5% sand…… 153

C2 Properties of cores made with 7% binder, 5% water, 0.5% cassava starch and 87.5% sand…… 153

D1 Proximate analysis of *cissus populnea*……. 153

D2 Fatty acids in *Cissus populnea*…….. 154

E1 Summary of baked tensile and compressive strength developed by various binders…….. 155

LIST OF PLATES

PLATE

AI Nursery of *Cissus populnea* plant…… 53

AII Fresh stems sprouting from matured stem…….. 53

AIII Matured Cut stems of *cissus populnea*……. 54

AIV Strands of *cissus populnea* removed from the stem……. 54

AV Milled powder from strands of *cissus populnea*…….

55

BI As cast surface finish of aluminium alloy casting utilizing 5%

cissus populnea as binder for both mould and core …… 117

BII As cast surface finish of aluminium alloy casting utilizing 5% *ciscus pulpnea* as binder for both mould and core production baked at 160^0C for 1hour…….. 117

BIII As cast surface of both the internal as well as the external walls of two aluminium castings whose moulds as well as cores were made from a binder of 5% *cissus populnea* … ……

118

BIV As-Cast internal surface of grey iron casting utilizing a core made from 7% *cissus populnea* (binder) and baked at 160^0C at a baking time of 1.5hours……..118

BV Sectioned As-Cast internal surface of grey iron casting utilizing a core made from 7% *cissus populnea* binder and baked at 180^0C at a

baking time of 1hour…….. 119

BVI As-Cast internal surface of grey iron casting utilizing a core made from 7% *cissus populnea* (binder) and baked at 200^0C at a baking time of 1hour…… 119

LIST OF APPENDICES **145**

Appendix A…….. 145

Appendix B…….. 147

Appendix C……. 153

Appendix D……. 153

Appendix E……. 155

LIST OF ABBREVIATIONS, SYMBOLS AND NOTATIONS

MNR	Ministry of Natural Resources
MOEE	Ministry of Environment and Energy
AFS	American Foundry society
GFN	Grain Fineness Number
RMRDC	Raw Materials and development Council
RWTH	Rheinisch-Westfalische Technische Hocshule
ASTM	American Society for Testing of Metals
RRTTC	Recycling and Reuse Technology Transfer Centre
CN	Cetane number
CP	Cloud point
PP	Pour point
FP	Flash point
GMBOND	General Motors Bond
LOI	Loss on Ignition
PUCB	Phenolic Urethane Cold Box
ED-XRFS	Energy Dispersion X-Ray Flourescence Spectrometry
Hr	hour
Hrs	hours
SS	Sum of Squares
Df	Degree of freedom
Ms	Mean Square
R	Coefficient

ANOVA	Analysis of Variance
T_b	Baking Time
w_b	Weight of Binder
t_b	Baking Time
X	Predicted Baked Tensile Strength
β_0	Intercept
β_1- β_7	Model coefficient for the input factor

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Foundry is the most basic input to the metal forming industry. Stringent demands of quality and quantity are being placed on it with rapid industrialization of other fields as mentioned above. Generally, foundry deals with the process of making castings in moulds formed in either sand or some other material. In the metal casting process, materials and design are of the utmost importance in creating a flawless part, but success also depends on the core. In the course of making castings containing hollow cavities, cores are employed.

For the purpose of sand casting, cores are sand shapes which form the contour of a casting that is not moulded with a pattern. They are thus used in forming internal cavities thus providing the casting process its ability to make most complex and intricate of shapes thus eliminating much machining (Dergamo *et al*., 2003; Hiene *et al*., 2004). Cores are also used in injection moulding.

If the wrong sand binder is used, cores can degrade too quickly resulting in malfunctioned part, or worse, not break down sufficiently when being removed. Both instances leave the foundry with useless scrap and wasted resources.

1.1.1 Application of Sand Cores

To produce cavities within a metal casting using sand cores as required for liquid cooling in engine blocks and cylinder heads. Special negative forms (core boxes) are used to produce sand cores. Cores can be made up from oil bonded sand, often basic oil such as

linseed oil can be used to make effective sand cores. Once made in the negative shaped core box the sand core is baked in an oven until it is cured.

Cores are inserted into the mould box after removal of the pattern from the sand. Whenever possible, foundry patterns are designed and made to avoid the use of cores, reducing the use of cores will reduce the mould set-up time and thus help to reduce labour costs in the foundry.

With a completed sand mould at the appropriate moisture content, the box containing the sand mould is then positioned ready to fill with molten metals such as iron, steel, bronze, brass, and aluminium alloy respectively.

After filling with molten metal the box is set aside until the metal is sufficiently cool to enable the removal of the hot casting from the sand mould.

When casting with metals like cast iron or lead, which are significantly heavier than the moulding sand, the flasks, called the cope and drag is covered with a heavy plate to prevent a problem known as mould floatation. Floating the mould occurs when the pressure of the metal pushes the sand above the mould cavity out of shape, causing the casting to fail. Sometimes mould box clips or flip locks are used to lock the boxes together to prevent loss of metal. The casting may be further strengthened by surface compression treatment such as shot peening, which adds resistance to tensile cracking and smoothens the rough surface, cast iron engine connecting rods are treated in this manner. After casting, the inner cores are broken up by rods or shot and removed from the casting. The metal from the sprue and risers is removed from the rough casting.

Various heat treatments may be applied to relieve stresses from the initial cooling and to add hardness; in the case of steel or cast iron, by quenching in water or oil.

Research on core binders reveals the variety of choices available today as well as critical factors that must be considered. The demand made on core making processes have risen sharply during the past few years and in many cases have undergone significant changes. Any technical and economic assessment of core making processes, today, must consider the entire manufacturing cycle, beginning with raw material sources and availability, up to the disposal of production wastes. According to Cobos (1996), published results from the institute of the Rheinisch-Westfalische Technische Hocshule (RWTH) and INASMET Institute of San Sebastian, Spain shows that the founder is sometimes overwhelmed by the wide variety of core making processes. Whichever method is used however, the foundry should expect its cores to have good dimensional stability. At the same time they should exhibit high strength levels during intermediate handling and must temporarily withstand high temperatures during the pouring operation. The binder should also exhibit complimentary compatibility with modifying agents, be capable of forming an acceptable level of carbon under pyrolysis conditions and exhibit a certain chemical reactivity.

1.2 STATEMENT OF THE RESEARCH PROBLEM

There are significant concentrations of airborne contaminants released in the air during metal pouring and decompositions of binders used for core making. These emissions are mostly from resin binder systems. Research by Ireland *et al.,* (2002) has shown that resins give better cores with accurate dimensions; however, their serious drawback is

hazardous pollutants emitted during the decomposition of these binders in addition to their use of corrosive acid catalyst as binders. These pollutants include benzene, Naphthalene, phenol, xylem, formaldehyde etc; and they pose serious health hazards (Bates, 2001).

Large volumes of gases and fumes are generated during pouring of the mould, (Bates, 2001). These gases are as a result of decomposition of the core binders as well as mould binders, (Busby, 1992). For this reason a binder should be developed which will not generate large volumes of gas during mould pouring, which will be environmentally friendly and will have the necessary strength to withstand the forces of molten metal in the mould. Some binders that have been developed locally have low baked tensile strength. Their tensile strength is improved when they are blended with one another. Suitability of *cissus populnea* as binder will be determined. If successful, it will add to the array of existing binders and compliment some of their advantages.

1.3 JUSTIFICATION FOR THE STUDY/SIGNIFICANCE OF THE STUDY

The foundry industry faces tough environmental challenges. Much time and energy go into foundry efforts towards addressing these challenges as part of the industry's overall commitment to the environment, as metal casting is one of the heaviest users of chemicals and other volatile substances (Bates, 2004). As a result hazardous pollutants and volatile organic compounds are released in the casting process. The foundry industry is desperately searching for an inexpensive, fast and strong binder that will hold up to metal casting conditions and which will not in the process emit smoke, smell or pollute the environment.

To meet the challenge of providing environmentally friendly core binders, a number of supplies have been introduced to technologies that are a promising step towards a new generation of binders that would both reduce the amount of volatile organic compounds and hazardous air pollutants released and yet do not compromise core strength and casting quality. Although progress has been recorded, but the issue of environmental pollution as a result of decomposition of core and sand binders using acid catalyst during casting still remains a problem (Bates, 2002). From the foregoing, there is the need to develop new core binding materials that will reduce the use of acid catalyst and be environmentally compliant.

1.4 OBJECTIVES OF THIS RESEARCH

The objective of this research is to study the possibility of using *Cissus populnea* as a core binder in foundry application. The properties of the cores so produced will be compared with standard values and those others developed locally to ascertain if it is suitable as binder or otherwise.

CHAPTER TWO

LITERATURE REVIEW

2.1. CORES

For the purpose of sand casting, sand cores are made up of sand grains, binder and water (for water based binders). The core so produced from these materials must satisfy the following conditions (Dergamo *et al.,* 2003; Jain 2003); (Reich 2005):

(i) It must have sufficient hardness as well as strength in both dry and green states. Without these properties, the core will not be able to support its own weight and withstand the forces of the molten metal.

(ii) Must be able to withstand the high temperature of the molten metal.

(iii) Must be permeable to allow the core gases to escape easily.

(iv) Should produce minimum amount of gas when in contact with molten metal so that the high permeability is not needed and greater strength is imparted to the core.

(v) Should be easily collapsible.

(vi) Must have good mixibility with core sand.

(vii) Should not adhere or stick to the core box.

(viii) Core sand should be easily reclaimable.

(ix) Should have good thermal dimensional stability.

One of the chief ingredients that will satisfy these requirements above is a core binder. There are many types of cores available. The selection of the correct type of core depends on production quantity, production rate, required precision, required surface finish, and the type of metal being used. For example, certain metals are sensitive to gases that are

given off by certain types of core sands; other metals have too low melting points to properly break down the binder for removal during the shakeout. Generally, there are green sand cores and dry sand cores.

2.1.1 Core Binder

A core binder is a bonding agent used as an additive to mould or core sand to impart strength of plasticity in a dry state. According to Jain (2003), core binder cements the grains of sand together into desired shape and also imparts sufficient strength to cores in order to fulfill the above conditions. Bauman (1989) stated that about 0.5-6% binder is required to achieve these objectives. However, binder content could be as high as 10% for heavy section cores.

Sarkar (1967) investigated various bonding agents with a view to finding the most effective contact point and concluded that the bonding medium in a core material is distributed around the sand grains so that, as far as possible, the particulate matters are completely coated by the bonding agent. This according to him was necessitated by the fact that the core involves the use of many particulate sand grains and no matter their orientation; there was an amount of bond available at all the points of contact thus ensuring uniform strength at all parts of the compacted core.

Core sand contain clay about 2 – 50% with suitable water content. The clay is the principal source of the strength and plasticity of the core sand. Therefore, clay is the binder; however in most cases additional binder is added to give the sand the desired bonding properties both in green and dry status. This is because clay has its limitations when used singly as a binder (Heine *et al.,* 2004). According to Kozlov (1989), core mixtures with high clay content as binder have a number of drawbacks among which are

poor gas permeability, increase in burn on sand defects on castings, poor yield ability and collapsibility.

Special binders are introduced into core sands to add strength. The oldest binder was vegetable oil, however now synthetic oil is used, in conjunction with cereal or clay. The core is then baked in a convection oven between 200 and 250°C. The heat causes the binder to cross-link or polymerize. While this process is simple, the dimensional accuracy is low (Dergamo *et al.,* 2003).

Another type of binder process is called the hot-box process, which uses a thermoset and catalyst for a binder. The sand with the binder is packed into a core box that is heated to approximately 230°C. The binder that touches the hot surface of the core box begins to cure within 10 to 30 seconds. Depending on the type of binder it may require further baking to fully cure (Dergamo *et al.,* 2003).

In a similar vein, the cold-box process uses a binder that is hardened through the use of special gases. The binder coated sand is packed into a core box and then sealed so that a curing gas can be introduced. These gases are often toxic (e. g. amine gas) or odorous (e.g. SO_2), so special handling systems must be used. However, because high temperatures are not required the core box can be made from metal, wood, or plastic. An added benefit is that hollow core can be formed if the gas is introduced via holes in the core surface which cause only the surface of the core to harden; the remaining sand is then just supplied out to be used again. For example, a cold-box sand casting core binder is sodium silicate which hardens on exposure to carbon dioxide (Dergamo *et al.,* 2003).

Special binders are used in air-set sands to produce cores at room temperature. These sands do not require a gas catalyst because organic binders and a curing catalyst are mixed together in the sand which initiates the curing process. The only disadvantage with this is that after the catalyst is mixed there is a short time to use the sand. A third way to produce room temperature cores is by shell molding. The term no-bake sands can refer to either the cold-box process or air-set process (Dergamo *et al.,* 2003).

2.1.2 Core Sand

Foundry sand consists primarily of clean, uniformly sized, high-quality silica sand or lake sand that is bonded to form moulds for ferrous (iron and steel) and nonferrous (copper, aluminum, brass) metal castings. Although these sands are clean prior to use, after casting they may contain ferrous particles (iron and steel).

The most common casting process used in the foundry industry is the sand cast system. Virtually all sand cast moulds for ferrous castings are of the green sand type. Green sand consists of high-quality silica sand, about 10 percent bentonite clay (as the binder), 2 to 5 percent water and about 5 percent sea coal (a carbonaceous mould additive to improve casting finish). The type of metal being cast determines which additives and what gradation of sand is used. The green sand used in the process constitutes upwards of 90 percent of the moulding materials used (AFS Report, 1991). In addition to high silica sands, there are also natural moulding sands in which clay is inherent in the material. The inherent clay acts as bond between the sand grains. There are also other types of special sands such as zircon, olivine, chamotte and chrome and chrome-magnesite sands. The

refractoriness of such sands is higher than that of silica sand hence they are used for casting steel and other ferrous alloys.

In addition to green sand moulds, chemically bonded sand cast systems are also used. These systems involve the use of one or more organic binders (usually proprietary) in conjunction with catalysts and different hardening/setting procedures. Foundry sand makes up about 97% of this mixture. Chemically bonded systems are most often used for "cores" (used to produce cavities that are not practical to produce by normal moulding operations) and for moulds for non ferrous castings.

2.1.2.1 Sieve analysis of foundry sands

Sieve analysis is carried out on core sands in order to determine the grain fineness of the sand. The grain fineness of silica sands ideal for making cores for the casting of cast iron is between 65 – 85 while for non ferrous and light alloys is between 70 –100 (Jain, 2003). The grain fineness number of Bacita silica sand is 78.62 while the refractoriness is 1575^0C (Shiedi and Ajuwa, 2008). That of River Niger behind Ajaokuta steel plant has been determined to be 32 (Ademoh, 2008), and Ochadama in Kogi state is 73.54 (Fayomi et al., 2011).

2.1.2.2 Physical Properties of Spent Foundry Sand

Typical physical properties of spent foundry sand from green sand systems are listed in Table 2.1.

Table 2.1. Typical physical properties of spent green foundry sand.

Property	Results	Test Method
Specific Gravity	2.39 – 2.55	ASTM D854
Bulk Relative Density, kg/m^3	2590 (160)	ASTM C48/AASHTO T84
Absorption, %	0.45	ASTM C128
Moisture Content, %	0.1 – 10.1	ASTM D2216
Clay Lumps and Friable Particles	1 – 44	ASTM C142/AASHTO T112
Coefficient of Permeability (cm/sec)	10^{-3} - 10^{-6}	AASHTO T215/ASTM D2434
Plastic limit/plastic index	Non plastic	AASHTO T90/ASTM D4318

Source: Javed and Lovell, (1994).

The grain size distribution of spent foundry sand is very uniform, with approximately 85% to 95% of the material between 0.6 mm and 0.15 mm (No. 30 and No. 100) sieve sizes. 5% to 12% of foundry sand can be expected to be smaller than 0.075 mm (No. 200 sieve). The particle shape is typically sub angular to round. Waste foundry sand gradations have been found to be too fine to satisfy some specifications for fine aggregate (AFS, 1991).

Spent foundry sand has low absorption and is non plastic. Reported values of absorption were found to vary widely, which can also be attributed to the presence of binders and additives (Javed and Lovell, 1994).

The content of organic impurities (particularly from sea coal binder systems) can vary widely and can be quite high. This may preclude its use in applications where organic impurities could be important (e.g., Portland cement concrete aggregate) (MOEE, 1993).

The specific gravity of foundry sand has been found to vary from 2.39 to 2.55. This variability has been attributed to the variability in fines and additive contents in different samples (Javed and Lovell, 1994).

In general, foundry sands are dry, with moisture contents less than 2%. A large fraction of clay lumps and friable particles have been reported, which are attributed to the lumps associated with the moulded sand, which are easily disintegrated in the test procedure. The variation in permeability, listed in Table 2.1 is a direct result of the fraction of fines in the samples collected (Javed and Loved, 1994).

2.1.2.3 Chemical Properties of Spent Foundry Sand

Spent foundry sand consists primarily of silica sand, coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins) and dust. Table 2.2 lists the chemical composition of a typical sample of spent foundry sand as determined by x-ray fluorescence (AFS, 1991).

Silica sand is hydrophilic and consequently attracts water to its surface. This property could lead to moisture-accelerated damage and associated stripping problems in an asphalt pavement. Antistripping additives may be required to counteract such problems (AFS, 1991).

Table 2.2, Foundry sand sample chemical oxide composition (AFS, 1991).

Constituent	Value (%)
SiO_2	87.91
Al_2O_3	4.70
Fe_2O_3	0.94
CaO	0.14
MgO	0.30
SO_3	0.09
Na_2O	0.19
K_2O	0.25
TiO_2	0.15
P_2O_5	0.00
Mn_2O_3	0.02
SrO	0.03
LOI	5.15 (0.45 to 9.47) 2.1 - 12.1
TOTAL	99.87

Depending on the binder and type of metal cast, the pH of spent foundry sand can vary from approximately 4 to 8 (Johnson, 1981). It has been reported that some spent foundry sands can be corrosive to metals (MNR, 1992).

Because of the presence of phenols in foundry sand, there is some concern that precipitation percolating through stockpiles could mobilize leachable fractions, resulting in phenol discharges into surface or ground water supplies. Foundry sand sources and stockpiles must be monitored to assess the need to establish controls for potential phenol discharges (Ham *et al.,* 1989); (MOEE, 1993).

2.1.2.4 Mechanical Properties of Spent Foundry Sand

Typical mechanical properties of spent foundry sand are listed in Table 2.3. Spent foundry sand has good durability characteristics as measured by low Micro-Deval abrasion, Ontario ministry of Transportation (1996), and magnesium sulphate soundness loss tests (ASSHTO Designation 1986). The Micro-Deval abrasion test is an attrition/abrasion test where a sample of the fine aggregate is placed in a stainless steel jar with water and steel bearings and rotated at 100 rpm for 15 minutes. The percentage loss has been determined to correlate very well with magnesium sulphate soundness and other physical properties.

Table 2.3. Typical mechanical properties of spent foundry sand (AFS, 1991).

Property	**Results**	**Test Method**
Micro-Deval Abrasion Loss, %	< 2	–
Magnesium Sulfate Soundness Loss, %	5 - 15 6 - 47	ASTM C88
Friction Angle (deg)	33 - 40	–
California Bearing Ratio, %	4 - 20	ASTM D1883

Recent studies have reported relatively high soundness loss, which is attributed to samples of bound sand loss and not a breakdown of individual sand particles (Javed and Lovell, 1994). The angle of shearing resistance (friction angle) of foundry sand has been reported to be in the range of 33 to 40 degrees, which is comparable to that of conventional sands (Javed and Lovell, 1994).

Silica sand is the most widely used moulding aggregate by the foundry industry. A common mistake by foundry men, and even researchers, is the concept that all silica sands possess the same physical properties and will behave the same during the casting process. Unfortunately, silica sands were not found to be equal in size and shape. Because of slight chemical alteration of silica sand, the performance and casting reliability is tremendously affected from different sources.

Two basic types of silica sand are commercially available for foundries. The first type is the round grain silica sand containing roughly 99% or higher of silica with minimal amounts of trace materials. The second type is the lake and bank sands. These sands contain approximately 94% silica with the balance containing iron oxide, lime, magnesia, and alumina.

Since impurities are removed, round grain sands possess higher refractoriness than the lake sands. However, because the higher refractoriness of the round grain sands, this can result in a higher propensity for veining and metal penetration defects. Lake and bank sands have lower refractoriness but also have a lower tendency for casting defects (Giese and Thiel, 2008).

Even within these groups of classifications, slight variations occur depending on location which imparts slight measurable difference in sand performance. It is difficult to say which sand is best, round grain or lake sand. Sand selection is determined by casting application, availability, and cost. Though a foundry might not consider lake sand, understanding how the impurities affect casting quality will assist foundries in selecting core sand additives for round grain sands to reduce the risk of veining and metal penetration defects.

Defects associated with expansion are veining and, to a minor degree, penetration. Generally, round grain sand users will combat penetration and veining problems by adding additives in the core sand mix. Typical additives include iron oxide. However, these additives mimic the properties of lake sand.

According to Giese and Thiel, (2008), the effect of natural impurities in silica sand is illustrated in figure 2.1. Both the round grain and bank sand expands at the same rate up to 593^{o}C, the point where quartz rapidly begins to change crystalline shape. Beyond this point, noticeable expansion characteristics can be observed. At approximately 649^{o}C, the linear expansion levels off. The bank sand has an expansion of 1.3% where the silica sand has an expansion of 1.6%, an appreciable difference. Also, notice the difference in the expansion curve for the lake sand. Expansion for the lake sand appears to occur earlier but at a lower total expansion than the bank sand. These differences between the sand can be attributed to the impurities in the lake and bank sand.

Research works at the Metal Casting Center exploring sand additives and blends have observed this similar behavior when different materials are added to round grain silica sand.

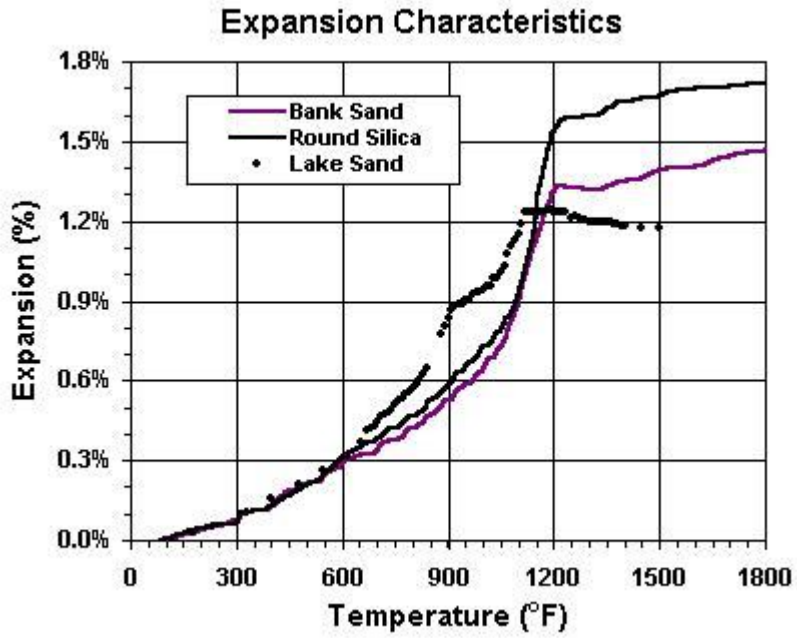


Figure 2.1 Expansion characteristics of different types of sand (Giese and Thiel, 2008)

Casting trials have shown that the bank sand has a lower propensity for veining defects compared to the round grain silica sand. Comparing the expansion characteristics between the two sands and the effect of veining, the rate of expansion and the total amount of expansion have an influence on controlling veining defects. According to Giese and Thiel, (2008), the Metal Casting Center, along with sand suppliers is developing a research program to obtain a better fundamental understanding of the expansion characteristic of sand. Key points, similar to that observed in cooling curve analysis, can indicate the performance of the sand. This can lead to the exploration of low cost sand additives to alter the expansion curve to prevent veining defects.

2.1.3 Ceramic Aggregate

Recycling and Reuse Technology Transfer Center, (RRTTC) and Carbo Ceramics have developed a new ceramic aggregate having similar characteristics as silica sand. According to Giese and Thiel, (2008), casting experiments performed by the Metal Casting Center has shown this material to have an increase resistance to sand expansion related defects and enhanced durability over other natural sand aggregates. For the Iowa foundry industry, the potential reduction of 1-3% average cost on scrap and rework can be realized in using the synthetic aggregate. Because of these unique properties, research work through the RRTTC is investigating the feasibility of designing a closed-loop core and moulding system. Coupled with present sand reclamation technologies, the spherical ceramic aggregate offers the potential for the Metal Casting Industry in reducing foundry wastes with lower energy costs. Higher waste landfill costs are anticipated to significantly increase in the next couple of years. The goal of the research programme is to reduce the amount of spent sand being sent to the landfill.

2.2 CLASSIFICATION OF CORE BINDERS

Core binders are generally classified into two broad based groups.

(i) Organic and

(ii) Inorganic.

Organic binder is further subdivided into natural and synthetic. The natural ones include oils, sugars, cereals, and molasses, amongst others while the synthetic ones include resins amongst others. Inorganic binders are also classed into natural and synthetic. The natural ones include fireclay, bentonites, amongst others while the synthetic ones include sodium

silicate, cement, plaster, phosphate binders, sulphite lye Silica Flour, Iron oxide amongst others (Jain, 2003); (Rabbii, 2001).

Advantages and disadvantages of Inorganic binders as given by Reich (2005), in Table 2.4,

Table 2.4: Advantages and disadvantages of inorganic binders, Reich (2005).

S/No	Component	Advantage	Disadvantage
1	Phosphate	Good solubility	No thermal strength
2	Borate	High strength	Sticking sand
3	Sulfate	Good solubility	Low strength
4	Silicate	Very high strength	Bad decomposition
5	Hydroxide/Carbon	Fast curing	Bad reclamation

2.2.1 Limitations of Core Binders in Use

Limitations of core binders in use has been enumerated by Khanna (2005). According to him some of the binders have excellent properties but when it comes to size of cores either small or big, they exhibit properties that tend to produce poor cores. The limitations of those in use locally are given below.

2.2.1.1 Sodium silicate/CO_2 process

Sodium Silicate otherwise known as water glass is probably the oldest core binder used in the foundry industry. The water glass method in combination with CO_2 gas or ester as a hardener has been used in iron, steel and non ferrous foundries since the 1950's, however, introduction of organic binders in the 1970's resulted in a marked drop in the demand for silicate binders. Sodium Silicate is mixed with sand in the proportions of 5-

8% and rammed. CO_2 gas is passed into the core, generally through a series of vents. The sodium silicate sets by the reaction:

$Na_2Si0_3 + CO_2 \rightarrow Na_2CO_3 + SiO_2$ (Rao, 2003).

According to Rao (2003), the disadvantages of this process are:

(i) Cores are difficult to break after casting as a result of their hardness.

(ii) Sand used by this method is not reclaimable.

(iii) CO_2 gas is very expensive.

(iv) Core size of section thickness less than 10mm cannot be produced.

However, the resultant cores or moulds are very sensitive to water and lose strength (damp back) on storage, will not accept aqueous washes. It is necessary to add breakdown agents such as sucrose and dextrin to promote better breakdown. Over-gassing produces very poor strengths (Naro, 2000).

According to Foseco's report (2008), more recent health and safety guidelines and increasing environmental legislation have led to a renaissance of this inorganic and odourless class of foundry binding agent. In this renewed approach, water glass is a silicic acid salt and is used in aqueous solutions containing different amounts of Na_2O and SiO_2 (modulus) as binding agent for sand. This obviously offers the advantage that all the toxic emissions originating from organic binding agents during the casting process can largely, and in some cases be completely, avoided.

The production of moulds and core using esters or CO_2 gas can also be described as odour-free, meaning that water glass and silicate binders can be classified as environmentally friendly binding agents. This renewed effort is yet to produce results that

will make the residual sand reclaimable and improve on the after casting characteristics of the core. Recent health and safety guidelines and increasing environmental legislation has led to a renaissance of this inorganic and odourless class of foundry binding agent. Foseco (2004) in their efforts to produce binders that have improved properties were able to improve the properties of silicate binders resulting in the following:

(i) lower cost

(ii) less toxic than conventional resin binder systems

(iii) no nitrogen, sulphur or phosphorous content

(iv) high resistance to hot tearing

(v) low viscosity

(vi) good compact ability

(vii) excellent breakdown characteristics

2.2.1.2 Starch

Starch is the major carbohydrate reserve in plant tubers and seed endosperm where it is found as granules (Buleon *et al.,* 1998), each typically containing several million amylopectin molecules accompanied by a much larger number of smaller amylose molecules. Starch is a polysaccharide (meaning "many sugars") made up of glucose units linked together to form long chains. The number of glucose molecules joined in a single starch molecule varies from five hundred to several hundred thousand, depending on the type of starch. Starch is the storage form of energy for plants, just as glycogen is the storage form of energy for animals.

The plant directs the starch molecules to the amyloplasts, where they are deposited to form granules. Thus, both in plants and in the extracted concentrate, starch exists as granules varying in diameter from 2 to 130 microns. The size and shape of the granule is characteristic of the plant from which it came and serves as a way of identifying the source of a particular starch.

By far the largest source of starch is corn (maize) with other commonly used sources being wheat, potato, tapioca and rice. Amylopectin (without amylose) can be isolated from 'waxy' maize starch whereas amylose (without amylopectin) is best isolated after specifically hydrolyzing the amylopectin with pullulanase.

Dry maize starch contains approximately 70% of starch and the production process requires separating the starch content from the fibre (hull of the grain), the gluten (protein) and the germ (Khana, 2003). The pure starch so obtained is seldom used in the foundry industry, but it is further treated to give it the desired properties. The starch is slurred in water, and the slurry passed through heated rolls. This gelatinizes the starch and after drying and grinding, the pre gelatinized product obtained is stable and possesses the ability to develop high viscosity solutions or gel when mixed with water. Genetic modification of starch crops has recently led to the development of starches with improved and targeted functionality.

Starch is one of the binding materials used in the core industry. It is available locally. Work done by (Khana, 2003), shows that its granules are not homogenous but contain two very similar polysaccharides namely;

(i) amylose (10 – 20% in maize starch) which may be leach out of water at 60 – 80% and

(ii) amylopectin (80 – 90% in cassava starch) which is insoluble in cold water, but forms starch paste with hot water. Although amylose may be dissolved out from the starch granule when separated from amylopectin, it retrogrades and becomes insoluble in water.

According to Jain (2003), by treating the starch with a dilute acid such as hydrochloric acid and heating at 120 -150^{o}C, the starch is polymerized and converted to dextrin. Dextrin may be up to 100% soluble in water depending on the degree of repolymerisation, where as pre gelatinized starches are insoluble or only very slightly soluble in water. Generally, foundry dextrins are 95-98% soluble in water. Both starch and dextrin additions increase the dry strength of the mix and greater dry strength are obtained with dextrin, particularly at the higher moisture content.

According to Achiv (2001), Starch binder reduces expansion defects and increased the wet strength of green cores considerably. Its drawback as highlighted by Aponbiede, (2000) is that it cannot be used singly as a binder to produce cores that will have enhanced strength to withstand the effect of molten metal.

2.2.1.3 Oils

They are the most popular core binders and are generally called core oils. These core oils are formulated from various ingredients such as vegetable oils, mineral oils and animal oils (Dergamo et al., 2003).

The core oil binders' needs to fulfill certain requirements amongst which are (Jain, 2003):

(i) Possess good dispersing properties so as to coat the grains of sand evenly

(ii) Work clean in core boxes

(iii) Produce cores with proper strength

(iv) Generate minimum amount of smoke and gas and respond to baking

(v) Produce good cores and economically viable.

One bad feature of most chemical specifications is that they set up chemical test values which make it impossible for the manufacturer of core binding materials to use any vegetable oils rather than linseed oil, tung oil, perrila oil, fish oil, and possibly oiticica and hempseed oils (Jain, 2003). Such vegetable oils such as soyabean oil etc are excluded because they have low iodine value, yet they produce very good cores.

A lot of research has been conducted using various blends of vegetable oils like peanuts, cotton seed, palm oil, palm kernel etc for the purpose of using them as binders. Aponbiede (2000) investigated these oils for the purpose of making cores and concluded that the cores so produced had low baked tensile strengths except in cases where they were blended with one another only then there was enhanced strength. Jain (2003) also established that core oils are used with cereal binders to enhance strength, a fact that had earlier been highlighted by (Aponbiede, 2000). The other drawback is that unpleasant fumes are generated during baking. These fumes could be poisonous (Heine *et al.*, 2004).

(a) Drying power of Oils – Iodine value.

It is very important to note that the drying property of oil is clearly indicated by its power to absorb oxygen, so that if it were possible to determine the amount of oxygen which any oil was capable of absorbing in a given time, we should be able to enumerate the various kinds according to their respective drying powers.

A direct method for their measurement is not yet possible, but valuable assistance is rendered by the fact that the unsaturated fatty acids in the vegetable oils which take up oxygen also absorb iodine to a similar degree in the presence of a third substance like carbon tetrachloride so that an estimation of the iodine absorbed by any oil is an indication of its drying power (Knothe *et al.,* 1995).

The drying power of any oil is measured by the iodine value, whereby iodine is bubbled through 100g of the oil for a definite amount of iodine that is expressed as the iodine value; table 2.5 (Knothe *et al.,* 1995).

Modern foundry practice demands that cores employing oils as binder be baked to obtain good tensile strength. In that connection great attention is paid to core oils as related to its drying power. Normal drying oils have iodine value above 130 as it is the case of Soya bean oil table 2.5 (Knothe *et al*., 1995). The semi drying oil, cotton seed and groundnut oils have on the other hand, have iodine value between 90 and 130.

(b) General Specifications of Core Oils

Soya bean oil, Cottonseed and Groundnut are subjected to various laboratory tests. Among them are specific gravity, flash point, fire point, viscosity, pour number, iodine number, moisture, impurities, saponification value, ash, odour, break test, melting point and others table 2.5 below.

Table 2.5 Properties of fats and oils and their iodine values Knothe *et al.*, 1995).

Fuel-related properties and iodine values of various fats and oils							
Oil or Fat	**Iodine Value**	**CN**	**HG** (kJ/kg)	**Viscosity** (mm 2/s)	**CP** (deg C)	**PP** (deg C)	**FP** (deg C)
Babassu	10-18	38	-	-	-	-	-
Castor	82-88	-	39500	297 (38 C)	-	-31.7	260
Fuel Coconut	6-12	-	-	-	-	-	-
Corn	103-140	37.6	39500	34.9 (38 C)	-1.1	-40.0	277
Cottonseed	90-119	41.8	39468	33.5 (38 C)	1.7	-15.0	234
Crambe	93	44.6	40482	53.6 (38 C)	10.0	-12.2	274
Linseed	168-204	34.6	39307	27.2 (38 C)	1.7	-15.0	241
Olive	75-94	-	-	-	-	-	-
Palm	35-61	42	-	-	-	-	-
Peanut	80-106	41.8	39782	39.6 (38 C)	12.8	-6.7	271
Rapeseed	94-120	37.6	39709	37.0 (38 C)	-3.9	-31.7	246
Safflower	126-152	41.3	39519	31.3 (38 C)	18.3	-6.7	260
High-oleic safflower	90-100	49.1	39516	41.2 (38 C)	-12.2	-20.6	293
Sesame	104-120	40.2	39349	35.5 (38 C)	-3.9	-9.4	260
Soybean	117-143	37.9	39623	32.6 (38 C)	-3.9	-12.2	254
Sunflower	110-143	37.1	39575	37.1 (38 C)	7.2	-15.0	274
Tallow	35-48	-	40054	51.15 (40 C)	-	-	201
No. 2 DF	-	47	45343	2.7 (38 C)	-15.0	-33.0	52

2.2.1.4 Molasses

Molasses, an eco-friendly material and relatively cheap binder material may be used as a substitute for chemical binders. It is a bye product of sugar refining and it is available locally. Cores made using molasses as a binder are poor in strength (Heine, *et al.,* 2004). In addition it is hygroscopic and therefore its use is not generally favoured when good castings are to be produced (Jain, 2003).

According to Heine *et al.,* (2004), cores made using molasses as binder level the core boxes well and give off little gas on casting the resultant cores are generally weak. They also suffer from fermentation which results in cores with variable strength. Wood extract behaves similarly to molasses without the presence of fermentation although they dry very rapidly on the bench.

Blending of these two materials is encouraged as they produce cores with enhanced strength. Molasses enhances the bench life of sands and imparts high dry strength and collapsibility. Due to high viscosity and wet ability, it also increases the green strength of sands. Mandal and Roy, (2006) made attempts to blend molasses and cement to prepare a core binder. Molasses was varied between 5.5% and 7.5% while cement was varied between 2% and 4%. Cores produced from this binder had baked strength of 518KN/m^2.

2.2.1.5 Linseed Oil

It is the most popular binder for core sand mixes. It is made by blending various ingredients such as vegetable, mineral and animal oils, natural resins and by product residue from vegetable based industries. The sand mix develops strength only when the prepared mix is heated to a temperature of about 200 – 240^{0}C, for a specified time which

may very from 1 to 3 hours (Heine *et al.,* 2004). The cores so prepared have very good baked strength, scratch hardness, permeability and collapsibility and can be stored for a long time. Linseed oil cores produce large amount of gas on casting (Jain, 2003).

Linseed oil can also be blended with other core binders towards enhancing the baked tensile strengths. In a study towards establishing the beneficial effects of addition of linseed oil to foundry sand cores bonded with Nigeria gum Arabic grades 2 and 4 Ademoh (2009), established that cores bonded with 3% grade 2 gum arabic and 3% linseed oil and baked for 2.5 hours developed a baked strength of 702KN/m^2

Those bonded with 3% grade 4 gum arabic and 3% linseed oil and baked for 2 hours developed a baked strength of 764KN/m^2. In each of the above cases, there is a 12% increase in tensile strength value for the admixed cores over those bonded singly with gum arabic grade 2 or 4.

Aponbiede (2004) also investigated the binding strength of Para rubber seed oil and Soya bean oil. He established a value of 656KN/m^2 and 1984KN/m^2 respectively being the baked strength of Soya bean oil and rubber seed oil respectively. The water content of the mixture was 7% in both cases while oil was 3%, cassava starch 0.5% baking temperature was 160^0C and baking time was 2 hours. The baked strength increased considerably when the starch content was increased to 2%. All other conditions remained the same. The strength obtained was 863KN/m^2 for Soya bean oil and 2622KN/m^2 for Para rubber seed oil; hence the latter is a good binder for core production when blended with about 2% cassava starch.

2.2.1.6 Synthetic resins

Synthetic resins are generally referred to as thermosetting plastics and are classed into phenol formaldehyde and urea formaldehyde amongst others. The former is a polymerization product of the organic compounds of phenol and formaldehyde while the later is also a polymerization product of urea and formaldehyde. These plastics are thermosetting and may be obtained as partially polymerized liquids or powders, when heated they polymerise to a strong solid and bake in a short time.

Initially, resins were thermosetting but as time went on foundry practitioners developed methods of making cores with resins using acid catalyst that did not require baking. The initial development of the no-bake binder concept was based on the need to provide foundries with a dimensionally accurate binder system that did not require heat to set, thus cutting down on expense and process steps. Over the years no-bake binders have continued to evolve and adapted to changing production, casting quality and environmental needs.

2.2.1.7 Other recent indigenous findings on core binders

Ademoh and Abdullahi (2008) investigated the suitability of Nigerian gum Arabic class 4 for its suitability as core binder. The results showed that a baked tensile strength of 900KN/m^2 was developed at a baking temperature of 200^0C and baking time of 2.5 hours at a binder content of 13%. According to them, these binders has other desirable properties like green compression strength, permeability, shatter index and collapsibility and are desirable for the casting of cast iron, steel and other non ferrous materials.

Olakanmi and Arome (2009) also investigated the characterization of the core binding properties of fatty- based oils specifically, melon and beniseed oils. According to them

baked compression strength of 3223.41KN/m^2 was developed. The oils also had other desirable attributes of bulk density, green compression strength and collapsibility. According to them these oils are suitable for making cores for the casting of both ferrous and non ferrous alloys.

Ademoh (2010) in his study of baked tensile strength properties of foundry cores bonded with hybridized binder that composed of neem oil and Nigerian gum arabic of various grades, a maximum strength of about 680KN/m^2 was developed by the blend (3% each of grade 4 gum arabic and neem oil) at a baking time of 2 hours and at a baking temperature of 200^0C. According to him, 3% each of grade 2 gum arabic and neem oil responded better by developing the required baked tensile strength within 1 hour as compared to other hybrid mixes.

Achiv *et al.,* (2010) investigated the bonding properties of *cissus populnea* for use as binder for the production of foundry cores for casting aluminium alloys. In their research efforts they were able to establish that 5% *cissus populnea* developed baked strength of 932KN/m^2 at a baking temperature of 160^0C and baking time of 1.5hours.

2.3 DRYING OF CORES

Drying increases the strength of cores and decreases the gas evolution on metal pouring. Cores are first cooled slowly to avoid surface cracking. The drying temperature depends on the kind of binder and curing time, on the shape and the wall thickness of cores. Cores made from organic binders are dried at between 160^0C – 400^0C, those made of sand resin mixtures at 200^0C – 280^0C and sand clay mixtures at 300^0C - 380^0C, (Dergamo *et al.,* 2003; Heine *et al.,* 2004; Jain, 2003; Kozlov, 1989).

According to Jain (2003), the drying process takes place in five distinct stages;

(i) Heating up to evaporation stage.

(ii) Moisture evaporation stage.

(iii) Heating up to drying stage.

(iv) Oxidation stage.

(v) Charring stage.

According to Heine *et al.,* (2004), proper baking is essential if a core is to perform satisfactorily when metal is poured. Under baked cores give off much gas and can cause variety of defects. Over baked cores may collapse too soon and break or erode before the casting is solidified.

2.4 NO-BAKE BINDERS

Over the past half century, a variety of no-bake binder systems have been developed predicated on a foundry's need to lower its overall costs. No bake binders have attacked this problem by addressing the casting quality, productivity and environmental attributes foundry men receive from their binder. Ireland *et al.,* (2002) have highlighted the strengths and weaknesses of three most commonly used no-bake binders with regards to productivity, casting quality and environmental acceptability.

2.4.1 Furan Binders

Furan binders were introduced in the late 1950s. The furan binder is based on furfuryl alcohol, a raw material derived from agricultural waste such as corn husk or rice hulls, and commonly cured with aryl sulfonic acids or phosphoric acid. Since this binder system does not require baking cycle to generate practical mechanical strength the furan binder has been acknowledged as the first true no bake binder.

Furan binders used in the cold box process are known for the high quality of their castings and excellent environmental properties. The limitations of the standard furan systems are its inability to work competitively in high production settings and to a lesser extent the sulfur dioxide emissions during the casting process, stemming from the arylsulfonic acid catalyst. According to Andrea Ferrero *et al.,* (1998), their experience at Teksid Aluminium Company showed that the acid catalysts compounds used during the furan hot box process to improve the speed of polymerization reactions release gases which are not friendly to the environment and the health of the core shop as well as foundry shop workers.

2.4.2 Phenolic - urethane

The phenolic urethane resin consists of no bake and gas cured resins. Both systems consist of two resin component. The first is diluted with 50% solvent while the second one is diluted with 25% solvent. The primary purpose of the solvent is to reduce binder viscosity, while the second reason is to enhance resin reactivity. The chemistry was introduced to the foundry industry in the 1970s and provided the basis for the first ever no-bake binder system capable of high speed production and fast strip times. The cure reaction takes place between a phenolic polyol and a polymeric isocyanate in the presence of an amine catalyst. The principle area of concern with this binder type has been and is still in its environmental properties. Due to the presence of solvents, it has high volatile organic compound emissions which often result in an offensive solvent odour during mould/core making and storage. In addition, the level of smoke and odour during pouring, cooling and shake out is comparatively high. The casting performance of the phenolic urethane is reasonably good.

2.4.3 Ester-Cured Phenolics

Growing pressure for environmental compliance has resulted in the development of ester cured phenolics binder system. The phenolic resole in the binder is cured by interaction with an ester co-reactant e.g. Triacetin.

The ester cured phenolic is water based; therefore it is very low in volatile organic compounds and has virtually no odour. Additionally, excellent casting properties, including outstanding surface finish, make ester cured phenolics a very suitable binder for steel casting applications. However, the difficulties associated with sand reclamation which is considered an important aspect of productivity, continue to limit the widespread use of this class of binder.

2.4.4 New Developments in No-Bake Binders

Advances in processes, metallurgy and particularly the development of chemical resin based systems have enabled the foundry industry to meet the demands of modern engineering by improvements in performance, productivity and dimensional accuracy. This has advanced foundry industry to the point where we are now classified as cast metal engineers. But the next challenge is already upon us – the challenge to meet increasing environmental and health legislation. The very nature of today's foundry processes involves the reaction of chemicals during curing of binders and subsequent pyrolysis during casting and shake out in addition to relatively high generation of waste. This combination makes the industry vulnerable to increasing stringent legislation both inside and outside the foundry in form of operator exposure limits, casting emissions and waste disposal.

Based on what has been said above, the ideal binder is one that combines high productivity with excellent casting quality while being environmentally very friendly. Defects in castings in some cases are as a result of the type of binder used. Oxides, bubble tails, and sub-surface porosity are some of the most aggravating defects encountered in castings. Some of these anomalies are difficult to detect and are often not found until castings are machined. According to Bates (2004), a blow hole and an associated oxide trail in a high performance head casting was found after the casting was machined. The gas came from a water jacket core, produced a layer of oxides, and collected in a boss where it produced a hole that was discovered during tapping.

2.4.4.1 New Furan Technology

High furfuryl alcohol content furan binders perform very well in terms of environmental acceptability, however, the inherent lack of flexibility of sand shapes made with this type of binder often results in cracking and breakage of the moulds and cores during handling. Urea formaldehyde and phenol formaldehyde polymers were used to improve the upfront and the ultimate tensile strengths of the furan binder. However, they do not impart the needed mechanical flexibility. The concept of incorporation of polymeric flexibilizers into the furan system resulted in much improved mould handling characteristics, resulting in reduced cracking and breakage. In addition to that, the incorporation of a modified urea formaldehyde resin has given rise to the design of a new binder, in the following referred to as a new furan Technology chemistry, which delivers cure speed similar to the phenolic urethane system while possessing environmental and casting attributes of furans (Ireland *et al.,* 2002). The new furan technology has enhanced performance with regards

to productivity, environmental acceptability and shows improvements in casting quality (Archibald, 1994), (Ireland *et al.,* 2002).

There is large amount of developmental work going on worldwide to improve the performance of core binders to make them more environmentally friendly. There is renewed interest in sodium silicate, modifications of the phenolic urethane cold box and alkaline phenolic resins, and new binders being introduced. Phenolic urethane cold box are the bench mark in the industry, and an industry's goal is to develop products that are as fast as phenolic urethane cold box, provide an equally good casting surface, improve shake out behaviours, and eliminate use of noxious gaseous catalyst and scrubbers.

2.4.4.2 Protein Based Binders

Protein based binders are a new class of organic binders which forms biopolymeric bonds when coated sand is mixed with water and rammed around a core box to form a core, Reich (2005). A protein based binder called GMBOND developed by General Motors Research and Development Centre and General Motors Power train Advanced Development Laboratories Andrea (1998); Bates (2003) uses a protein based biopolymer and is a dry, fine, slightly tan water soluble powder. No toxic gases are involved in core production which greatly improved the environment around the core machines. The cores are made by removing moisture with heat (Bates, 2004). According to Reich (2005) the bonds of core made with GMBOND sets by dehydration rather than a chemical reaction, the aggregate surface chemistry has little effect on strength or bench life. Also the bond is reversible which allows for recycling of scrapped cores. In fact, GMBOND coated sand can be reused several times without loss of integrity and will biodegrade in spent sand.

GMBOND uses both silica sand and synthetic aggregate; it offers comparable dimensional accuracy and tensile strength to a baseline phenolic urethane cold box binder coated with silica sand. During casting, GMBOND offers excellent dimensional and hot strength properties. Because it is not thermoplastic, it does not deflect or warp when heated like thermo set resin systems. This is due to the semi crystalline structure it gains when cured. The binder's transverse strength decreases more quickly than the phenolic urethane cold box binder does with heat over time so does not require hammering or bake out for core removal. This allows material to be removed easily and minimizes the likelihood of unwanted core sand in the casting.

The easier core removal and tighter dimensional accuracy allows thinner casting walls to be employed to remove weight from the cast part, further reducing the component's cost. These qualities benefit high-volume foundries by saving time, reducing energy cost by eliminating shake out, and reducing damage caused during core removal. This attributes particularly benefit foundries casting non ferrous metals which are cast at lower temperature range; easier core removal can also help speed production rates.

2.5 CHARACTERISTICS OF CORES USED IN PRODUCING ALUMINUM CASTINGS

During the last few years, the sale of aluminum castings has grown at a rate of approximately three times that of iron or steel castings. Vehicle manufacturers world wide are striving to produce vehicles that are light in weight without compromising quality and durability. The result of this growth has been lighter, more fuel efficient cars and light trucks (Carney, 2008); (Brooke and Evans, 2009); (Gehm, 2009). According to Giese and Thiel (2008) the metal casting centre working with Borden Chemical, a major

supplier of sand binders to the foundry industry has been working on improving the characteristics of cores used in producing aluminum castings.

One of the major problems encountered in casting aluminum alloys is that cores used are predominately produced from phenolic urethane binders. These binders have high hot strength and, as in the case of aluminum castings, are not heated with the pouring of the castings to temperatures that break down the bonds between the sand grains. The result of this is that cores are difficult to remove from the solidified castings.

In their research work at Teksid Aluminium Company, Andrea Ferrero *et al.,* (1998) also established that due to the relatively low metal temperatures to which resin binders are exposed to during aluminium casting, oxidation and breakdown of the binder during pouring and cooling of the casting is very limited. The cores appear to be very strong after casting and removal is not straight forward, often requiring long cycle time operations and sometimes careful inspection to ensure completely sand free castings.

Current methods used to remove the cores are both energy intensive and have the possibility of damaging fragile components. We are evaluating changes in binder formulations in an effort to reduce or eliminate these problems. Possible benefits of the research also include reduced buildup of resins on the core equipment used to produce the cores and better dimensional stability (Giese and Thiel, 2008).

2.6 CASTING DEFECTS ASSOCIATED WITH CORE BINDERS

Gases evolved with the use of binders create problems, but gas release rate, composition, volume, mould permeability are among defect causing factors. It is generally accepted that the gases present at the mould-metal interface are important determinants in the severity of gas defects found in metal casting (Rahmoeller, 1993).

Naro (2000) observed that Phenol resins using benzilic ether polyol and methylene diphenyl diisocyanate as binders produces certain casting defects such as pin holing caused by the nitrogen content of the binder which reduces to ammonia in the casting environment and dissolves in the molten metal and is evolved as small blow holes on cooling; "graphitic defect" which is a deposit of graphite carbon which collects in flakes on the surface of the casting; and "finning" or "veining" caused by the mould or core cracking under the expansion stresses during casting and molten metal running into the cracks. According to Rahmoeller (1993; Naro 2000), it is generally accepted that the gases present at the mould metal interface are important determinants in the severity of gas defects found in a metal casting. He further documented that resins containing nitrogen have long been associated with the production of nitrogen pinholes in iron. Unfortunately, due to the difficulty in designing experimental methods to measure consistently the effects of these gases, it has been impossible to fully understand the relationships between the binder, casting conditions and resulting pinhole severity.

2.6.1 Surface and Subsurface Gas Defects

Surface and subsurface gas defects have always been common and troublesome defects in grey and ductile iron castings poured in green sand moulds. They cause significant amount of scrap in the casting industry. In general, gas porosity can originate inside or outside the metal being poured.

According to Naro (2000) exogenous sources include:

(i) Air initially in the mould cavity that was entrained during pouring,

(ii) hydrogen and other gases produced by metal-mould reactions,

(iii) Reaction of metal with chaplets, and

(iv) Gases emitted by cores and coatings.

Scarber and Bates (2006) gave the endogenous sources to include:

(i) Gases formed by precipitation of dissolved gas, and

(ii) Those formed by chemical reactions, such as hydrogen formed between liquid metal and moisture in the mould or air as described by the following equation for aluminium

$$2Al + 3H_2O \rightarrow Al_2O_3 + 6[H]$$

Binder pyrolysis can inject gas into the metal, and the gas is usually entrapped near the cope surface or under cores. Since gas bubbles may float some distance before becoming entrapped, identifying the source is sometimes difficult (Naro, 2000).

Gases may be trapped if they are evolved while the metal is completely liquid, but they can damage the casting by leaving an oxide trail, dross or dissolved gas (Campbell, 1997).

During the past thirty years, innovations in synthetic binder technology have resulted in movement away from green sand moulding towards total no bake moulding and core making processes and accompanying new type of casting defects (Naro, 2000). Shortly after the introduction of cold box phenolic urethane binders, casting defects generally described as severely wrinkled surface defects were reported by some of the early users of these binders. A few foundries also reported "Leakers" in pressure tight castings. The technical literature of the time contained little information regarding the specific conditions that increased the likelihood of these defects, soon to be known as "Lustrous carbon" or methods known to eliminate these defects. The available information

suggested that defect formation is affected by pouring time and gating system design. Slow, turbulent filling and low pouring temperatures were reported to aggravate defect formation (Bates, 2004).

Earlier investigations carried out by Moll (1987) proved that the lustrous carbon defect was as a result of the usage of binders that evolved large quantities of carbonaceous decomposition products during the filling of the mould by molten metal. Such carbonaceous residue however, can be beneficial when present in less amounts as they provide a reducing atmosphere that minimizes oxidation at the mould – metal interface and generally improves casting surface finish and peel.

It is also reported that porosity formation in grey iron castings is as a result of mould metal reactions between evolved mould and core gases at the solidifying casting surface (Naro, 2000). The appearance of sub surface porosity defects resulting from the use of resin binders may take numerous shapes but usually form as either small, spherical holes (sometimes elongated or pear-shaped) and called pinholes or larger irregularly rounded holes or irregularly shaped fissure type defects. The gases normally held responsible for subsurface porosity defects are nitrogen and hydrogen (Naro, 1999).

Naro (2000) in his study of pin holes in grey cast iron observed that the frequent causes of pin holes as a result of core binder are:

(i) Binder with too high nitrogen and hydrogen content

(ii) Too much binder in the sand and

(iii) Wrong mixture of binder aggregates.

According to him, the most successful solution is to change the sand and not the metallurgy. So the application of nitrogen stabilizing elements which include titanium

and or serium, zirconium does not give the desired result. As mentioned if such remedy is applied, there will be higher danger to form D-graphite in grey iron.

2.6.2 Permeability of Cores

A core is made up of permeable mass consisting of many grains of material with interconnected voids between them. The size of the voids, the degree of interconnection and the distance through them which the gas has to travel determines the rate of flow of gas through the mould, this venting property being termed permeability.

Permeability of core sand is an essential property and its value should be as high as possible. Although the permeability of core sand depend primarily on size and shape of the sand grains and the clay content, the required values would not be realized unless the correct quantity of water were mixed with the sand and the sand itself were rammed to a particular degree of hardness. According to Jain (2003) if the sand hardness number does not exceed 85, it is observed that the product of the hardness number and the permeability remains a constant. Therefore, the permeability of any sand may be found by comparing the sample with a standard sand specimen whose hardness number and permeability number are known.

The widespread and increasing use of resin sand binders for mould and core making process, together with the use of spirit based organically bonded dressings has given rise to many problems connected with high gas evolution during pouring of mould. In turn this had caused foundries to pay closer attention to venting and mould permeability. During the filling of mould with molten metal, gases are evolved from several sources and must be removed from the mould cavity if the incoming metal is to fill it completely. According to Naro (2000) the four major sources of gas are as follows:

(i) Steam produced from water in green sand mould,

(ii) Gases produced from decomposition of binders and sand additives in the mould and core,

(iii) Mould and core coatings,

(iv) Air that is in the mould cavity before casting.

The reactions which evolve gas are dependent on heat and will be most pronounced during and just after casting the metal. If the gas cannot vent away freely, it is in this period that defects in the form of incompletely filled moulds or voids in the metal due to gas blowing into it can be produced in the castings.

In the recent times, developments in moulding and core making technology have allowed foundries to cast parts with much greater intricacy and better dimensional accuracy than ever before. More intricate castings generally have larger core surface areas in contact with molten metal during casting. Venting the cores becomes increasingly challenging as the complexity of the castings increases. And, the difficulty of venting cores increases the tendency for gas defect formation.

According to Bates *et al.,* (2008) to understand and reduce the incidence of gas defects in cored castings, improvements are needed in three areas:

(i) Better measurement of sand permeability;

(ii) Reliable data on the rate and type of gas evolved; and,

(iii) Methods for calculating gas pressures inside cores.

The effect of permeability on pressure inside cores has been extensively studied by Naro and Pelfrey (1983). Based on data developed by them, the gas pressure in molds poured

with steel decreased exponentially with increase in core permeability. They also investigated the tendency for blow-hole formation with changes in the core sand-grain fineness number (AFS-GFN), and found that the incidence of blows increased with the grain fineness number. It was also found that the permeability increased with a decrease in sand-grain fineness.

Before then Levelink *et al.,* (1981) measured the pressure inside cores using a probe in the sand and verified that the internal pressure decreased with an increase in permeability. However, it was difficult to quantify the effect of permeability because of the lack of data on the rate of gas generation and the properties of the gas evolved.

A technique also developed by Winardi *et al.,* (2005) for measuring the permeability of sand with these factors in mind. The technique measures the ability of gas to flow through pores in cores, and separates the contributions of the type of gas, gas temperature, core geometry, and porosity on core permeability.

The total gas volume produced during loss-on-ignition (LOI) measurements has been used to predict pressures. However, the gas volumes could not be converted directly into rates of evolution in molds and cores because LOI measurements were made at relatively low heating rates. Levelink *et al.,* (1981) earlier noted that the heat-transfer rate to the core in the casting process was much higher than the heat transfer rate to core samples in a furnace. Hence, gas-evolution rates produced using tube furnace procedures would be expected to be lower than rates in a mould or core.

Research by Bates *et al.,* (2008) show that the pressure developed inside the core increases with a larger core-metal contact area, distance to core print, and gas-evolution rate. The pressure decreased with an increase in core print area and sand permeability.

However, the variables influencing the rate of gas generation during core-metal contact have not been documented. They gave the following factors to be responsible for gas evolution in the mould.

2.6.2.1 Effects of core age

Core age can significantly affect the amount of gas that evolves. Phenolic urethane cold box (PUCB) cores placed in contact with aluminum immediately after blowing produced higher rates and volumes. The peak rates obtained after one day and after 10 days were 35 and 6cm^3/sec., respectively. The gas volumes were about 300 and 200 cm^3 after the same aging. The lower rates of gas evolution associated with aged cores was probably associated some solvent evaporation and with greater cross-linking of the resin. Although each core was aged in a sealed bag, still some volatiles might be lost with time. Binders with a higher degree of cross linking are also thought to need more energy to pyrolyze, and this might reduce the volume of gas produced. More information is needed to minimize speculation, and such an investigation should involve determining the gases evolved as a function of core age.

2.6.2.2 Effect of sand permeability

Core permeability do not affect the volume or rate of gas evolution. The gas-evolution rate and total volume evolved from PUCB cores made with 50 and 75 GFN were similar at 34 cm^3/ sec. and 290 cm^3, respectively. The permeability generally decreases as sand-grain size number (GFN) increases. Although permeability does not affect the amount of gas evolved, it is still an important parameter because it influences the pressure developed in the core as the binder decomposes. Lower permeability cores develop higher internal pressures if other casting parameters are held constant.

2.6.2.3 Effect of measurement

Gas-evolution rates from cores were measured and found to be affected by metal contact area, core age, modulus, and metal temperature. The core metal contact area was the most significant variable affecting heat transfer from the metal into the core. Cores in contact with higher-temperature metal also produced more gas. The gas-evolution rates were not affected by the core permeability.

These data are being used to develop a model to describe gas evolution from cores as a function of geometry and contact area with metal. The goal is to predict the gas pressure inside cores. If the gas pressure exceeds the metal head pressure, gas will be blown into the metal, resulting in hydrogen absorption, blow holes, pinholes, and oxide trails in aluminum castings. A model is being developed to take into account the chemical reactions, evaporation, condensation, and re-evaporation of volatile compounds in cores.

2.7.3 Permeability Limitations

It is very difficult to specify any hard and fast figures for the permeability of moulds and cores for a particular casting or foundry. According to Busby (1993) it is normal to expect naturally bonded moulding sand to give permeability numbers of 20-30 and synthetic moulding sands of 80-120. It is risky to have permeability less than 20 in green sands as there is no margin for error in water content. At the other end of if the permeability of over 120 are used on synthetic sands a rough surface finish to the casting will result.

According to Heine *et al.,* (2004) the average grain size of the sand could be related to the incidence of metal penetration at a given casting height.

It should be noted that most binders and additions made to improve the sand properties or surface finish of the casting are in liquid or powder form and will fill the pore spaces in a similar way to a fine casting. There is an exception to this in that small amounts of liquid added to dry sand will give it a small amount of green strength resulting in a lower compaction density and an increase in permeability. It is not generally appreciated that very variable quantities of gas may be evolved from organic binders according to their composition, curing treatment, and decomposition rate. Since sands on their own have none or virtually no gas evolution, practically all the gases given off from a bonded sand comes from the material added to the sand to bind it together.

2.6.4 Porosity Defects

Porosity defects are chemical in nature and result when liquid metal becomes supersaturated with dissolved gases during melting or pouring. The ensuing discontinuities are present as discreet voids that may be rounded or irregularly shaped in the solidified casting and generally lie just under the casting surface. In some cases it is mistaken for blowholes, a physical or mechanical problem related to the inability of the decomposed mould and core gases to escape from the mould cavity, either through permeability or venting (Naro, 2000).

Tiny gas bubbles are called porosities, but larger gas bubbles are called blowhole*s* or blisters. Such defects can be caused by air entrained in the melt, steam or smoke from the casting sand, other gasses from the melt or mould. (Vacuum holes caused by metal shrinkage may also be loosely referred to as 'blowholes'). Proper foundry practices, including melt preparation and mould design, can reduce the occurrence of these defects.

Because they are often surrounded by a skin of sound metal, blowholes may be difficult to detect, requiring harmonic, ultrasonic, magnetic, or X-ray analysis (Stefanescu, 2008).

A survey conducted by Bates (2007) the metal casting industry's need for improvement lies in eliminating porosity in castings. In this survey, concerns over porosity defects rated twice as high as any other issue in the survey. The porosity concerns enumerated are generated from several sources including gases released from core binders during casting operations. According to Naro (2000) the variables affecting the formation of binder related porosity defects which are as a result of binder misuse include:

(i) infrequent calibration of binder pumps and sand flow rates on continuous mixers,

(ii) general equipment malfunctions related to binder pumps, worn mixer auger screws or blades, poor house keeping practice,

(iii) intentional unbalancing of binder components to facilitate striping, and

(iv) general misunderstanding of possible potential consequences resulting from any of the preceding.

According to Naro (2002) three major sources may contribute to porosity formation in grey iron castings. These are:

(i) High initial gas content of the melt originating either from the charge ingredients, melting practice or atmospheric humidity,

(ii) Reaction of carbon and dissolved oxygen under certain melt conditions, and

(iii) Mould- metal reactions between evolved mould and core gases at the solidifying casting surface.

In addition any combination of these three sources may have a cumulative effect on promoting porosity formation. However, the gases normally held responsible for subsurface porosity defects are nitrogen and hydrogen (Naro, 1999). In another study conducted by Naro (2000) during the casting of grey graphite iron, the frequent causes of porosity in castings using resin binders are:

(i) binder with too high nitrogen and hydrogen content

(ii) too much binder in the sand

(iii) Wrong type of binder for the metal being cast.

According to him, the most successful solution is to use fresh sand as against changing the metallurgy. Addition of nitrogen stabilizing elements such as Ti, Se, or Zr does not give the desired results; rather D graphite iron will be formed in Grey iron.

Lemon et al (1983) and latter Bates (2007), in highlighting issues on porosity formation in castings in a conference reported the findings of Leonard Winardi (2005) whose focus was on porosity produced by excess gas pressures in moulds and cores. Leonard Winardi (2005) developed three techniques for determining the gas pressure in moulds. These include inserting a probe attached to a pressure transducer in cores; immersing samples in molten metal to various depths, depending on the calculated gas pressure in the mold or core; and observing whether or not bubbles were ejected and observing gas evolution from cores during pouring in a real-time X-ray unit. Any or all of these three techniques was used to determine peak pressures, at least in simple cores.

Winardi (2005) measured the volume and rate of gas evolution from a core produced in a commercial foundry, and calculated the pressure inside the core as a function of time.

The binder being used produced two gas evolution peaks which resulted in two gas pressure peaks. The peak calculated pressure was almost identical to the peak measured pressure. Further improvements in the shape of the pressure curves may be obtained when more accurate information on the composition of the gases produced is obtained.

Winardi's theory of gas bubble formation in castings is that if the gas pressure in the mould or core exceeds the metal head pressure, gas will bubble from the core or mould into the metal. If the metal head pressure can be developed faster than the gas pressure, then the release of gases into the mould cavity is suppressed, and gas is forced through the core prints. If the pouring rate is lower, then the gas pressure exceeds the metal head pressure for a period, and during this time, gas bubbles through the metal to produce dross, oxide folds, and slag defects. The importance of the peak rate of gas evolution in relation to the pouring rate helps to explain why gas defects can sometimes be eliminated by gate changes to pour the casting faster. Sometimes, blows also can be eliminated by pouring hotter to allow the bubbles to blow through the metal. This does not eliminate dross formation, but it may allow the gas to exit the casting.

Bates (2007) presented data on the volumes and rates of gas evolution from a variety of cores in contact with aluminum, iron, and steel, from which pressures were calculated. Two such curves were obtained when an epoxy acrylic resin-bonded core came in contact with iron. The resin bonded sample produced gas evolution rates of up to 15cc/sec., about 10 seconds after contact with iron at 1316°C. A coated core that had been dried in a foundry produced the gas evolution volumes and rates. The dried coating moved the peak rate to a shorter time after contact, and increased the peak rate to about 26cc/ sec. The

high peak rate and short time after pouring would aggravate the tendency for the gas produced to blow into the metal before a skin could be formed.

Finally he outlined an approach for using core gas evolution data from simple cores to model the core pressure in complex cores, such as water jacket cores and oil passages. Bates can approximate the gas pressure inside cores from first principles of resin pyrolysis using hydrogen evolution and water decomposition. He outlined further work needed, including model verification in foundries, and making the code input and output more user friendly.

The appearance of subsurface porosity defects resulting from the preceding sources may take numerous shapes but usually form as either small, spherical holes (sometimes elongated or pear-shaped) and called pinholes, or larger, irregularly rounded holes or irregularly fissured type defects (Yu, 2002). According to Campbell (2003) the internal surfaces of the resultant holes may be:

(i) Oxidized

(ii) Lined with shiny graphite film or

(iii) Contain slag or manganese sulfide inclusions.

According to Naro (1999) a lot of technical literature contains a large amount of work describing porosity defects and the metallurgical practices that promote the occurrence and treatment of such defects, relatively little experimental work had been conducted in the area of chemical binder induced mould-metal interface porosity reactions. Investigations that have been conducted in this area have been generally limited to discussions that potential problems exist when using high nitrogen (urea) furans, and to a lesser extent, shell and oil-alkyd-isocyanate systems.

Hydrogen, nitrogen, oxygen and carbon, may react or combine in numerous ways to provide the necessary conditions that favour porosity formation (Yu, 2002). According to Naro (2000) the following gaseous reactions are thermodynamically possible and under the right conditions may occur at the mould- metal interface:

Binder → H (nascent) → H_2 (g)

Binder → N (nascent) → N_2 (g)

Fe + H_2O vapour (binder) → FeO + 2H (nascent)

$3H_2$ (binder) + N_2 (binder) > $2NH_3$ (g) → 6H (nascent) + 2N (nascent)

FeO + C (binder) → CO (g) + Fe.

While the first four reactions are likely to provide both surface and subsurface porosity defects the last reaction usually results only in surface defects, such as pock marking or more frequently, lustrous carbon laps and wrinkles (Naro, 2002). When an organic binder thermally degrades, hydrogen and nitrogen are liberated in the nascent or atomic form. In this mono atomic state, they are readily soluble in molten iron, and if present, dissolve quite easily in both molten grey iron and ductile irons. If ammonia forms, it also may dissociate into both nascent hydrogen and nitrogen. Since the solubility of hydrogen and nitrogen in liquid iron is far greater than in solid iron, these gases may precipitate out of solution as gas bubbles during solidification if they are present in amounts greater than the solid solubility limits. The shapes of the resulting gas holes may vary from small widely dispersed spherical shaped holes lying just under the surface to numerous fissure type holes, often resembling shrinkage defects and are usually perpendicular to the casting surface. In either case, absorption of nitrogen and or hydrogen by the molten iron, either individually or jointly, may result in subsurface porosity defects.

2.7 *CISSUS POPULNEA*

Cissus populnea is a plant that grows in the savannah region of Northern Nigeria. It was identified through personal conversation by F.A. Tiseer (Ph.D) of the Biological Sciences Department of Ahmadu Bello University, Zaria. It is called Ager in Tiv, Loda in Hausa and Okoho in Idoma. Like other plants, the seeds germinate and grow on their own in the bush also, matured stems of the plant can also be cut in lengths varying from 250mm, buried in the soil dug about 100mm deep and watered adequately to germinate. It grows best when planted by the side of a tree so that as it grows, its growth direction follows the height of the tree. Its maturity period is about 9 months, there after; it remains for years for as long as there is enough water for it to continue growing. It is an edible plant among a cross section of Nigerians. It is used to make soup, a local delicacy eaten by the people of North Central Nigeria and some tribes in North East as well as North Western parts of Nigeria. Plates AI, AII, AIII, AIV and AV shows the nursery of *cissus populnea* plant, fresh stems sprouting from matured stem, matured cut stems, strands peeled from the matured cut stem and the milled powder from the stem respectively.

For the fact that it is consumed as soup alone without any reported case of an ailment associated with its consumption, in addition to the fact that it is an Eco-friendly material and environmentally safe, its use as binder will have no negative effect on the environment. It will also not pose any health risk as opposed to resins which evolve large amount of harmful gases and degrades the environment (Bates, 2002).



Plate AI: Nursery of *cissus populnea* plant.



Plate AII: Fresh stems sprouting from matured stem



Plate AIII: Matured cut stems of *cissus populnea*.



Plate AIV: Strands of *cissus populnea* removed from the matured stem.



Plate AV: Milled powder from strands of *cissus populnea*.

2.8 CORE PRODUCTION

A core is that portion of the mould which forms the hollow interior of the casting or a hole through the casting (Jain, 2003). For sand cores, the ingredients are sand and binder. Silica sand with minimum amount of clay is considered most appropriate for use in making cores. If the clay in the sand is in excess it will reduce permeability and collapsibility.

In selecting the sand to use, the following factors are considered: shape, size, distribution of sand grains, the clay content and mineralogical composition of clay particles.

The sand binder is to cement the grains of sand into the desired shape and to impart sufficient strength to the cores to prevent breakage, distortion and erosion in the core

making, moulding and casting processes. In addition the sand mixture should possess permeability, collapsibility and heat resistance.

The core is made by mixing sufficient quantities of water, binder and sand together (for water based cores) or by mixing the binder and sand then adding a catalyst to speed up the reaction (chemical cores). Thereafter, the cores are baked to remove moisture. The no bake or chemical cores are ready for use or storage on removal from the core box.

There are split cores and single piece cores. The split cores are made in pieces and assembled together by gluing while the single cores are made in a single unit. Cores are also classified according to their shape and position in the mould. This category of classification is made up of horizontal core, vertical core, balanced core, cover core, hanging core, stop- off core, ram- up core and kiss core.

2.9 MECHANICAL PROPERTIES OF FOUNDRY SAND CORES.

A lot of research work has been done to ascertain mechanical properties of sand cores for use in the foundry industry generally. Ademoh (2009); Busby (1993); Titov and Stepanov (1982) have developed mechanical properties of foundry cores. These properties are summerised in Tables 2.6 and 2.7. Irrespective of the type of sand, binder and other foundry parameters, good mechanical properties of foundry sand cores should be within the limits specified (Ademoh, 2010). Table 2.8 refers to classes of Iron/ steel casting by weight (Sosnenko, 2001).

Table 2.6: Mechanical Property ranges of foundry sand cores.

Alloy Casting	**Permeability Number**	**Green Compression Strength (KN/m^2)**	**Baked Tensile Strength (KN/m^2)**
Class I iron/steel cores	130 – 150	3 – 6	700 - 1000
Class II iron/steel cores	100	5 – 10	500 – 700
Class III iron/steel cores	100	10 – 16	350 – 600
Class IV iron/steel cores	70	15 – 25	200 – 300
Class V iron/steel cores	70	20 – 35	80 – 150
Copper bronzes cores	90	3 – 5	400 – 600
Copper brasses cores	60	6 – 8	500 – 700
Intricate aluminium cores	100	3 – 7	500 – 700
Non-intricate aluminium cores	80	6 – 15	400 – 600
Magnesium cores	80	60 - 150	300 - 500

Source: Ademoh, (2009); Titov and Stepanov (1982).

Table 2.7: Baked tensile strength of foundry sand cores (Busby, 1993).

Alloy Casting	**Baked Tensile Strength (KN/m^2)**
Class I iron/steel cores	700 - 1000
Class II iron/steel cores	500 – 700
Class III iron/steel cores	350 – 600
Class IV iron/steel cores	200 – 300
Class V iron/steel cores	80 – 150
Copper bronzes cores	400 – 600
Copper brasses cores	500 – 700
Intricate aluminium cores	500 – 700
Non-intricate aluminium cores	400 – 600
Magnesium cores	300 - 500

Table 2.8. Classes of Iron/Steel castings by weight: (Sosnenko, 2001).

S/NO	WEIGHT OF CASTING Kg	CLASS
1	Up to 50	I
2	50 - 100	II
3	100 - 500	III
4	500 - 1000	IV
5	1000 – 10,000	V

2.10 MECHANISM OF BONDING

Engineering materials possess interatomic attractions which lead to atomic bonding. If there were no such attractions, each atom would behave independently. Furthermore, materials would have neither coherence nor resistance to externally applied forces. It is convenient to identify four general types of interatomic bonds. The first three (ionic, covalent and metallic) are called primary bonds because they are relatively strong. Each is a direct consequence of the exchange or sharing of valence electrons which lie in the S and P orbitals. The fourth bond category which is van der waals include several variants of weaker, but important attractive forces (Vlack, 1980).

The mechanism of bonding as applied to sand mixes involving binders is an important step in the production of quality castings. Mixing sand aggregate and addition of binders should be completed within the shortest time possible in order to avoid water loss. The order of addition is important only when the green binder is added as a powder. In this case the powder should not be added first, since mixing of two granular materials differing in size as much as sand on the one hand and powdered binder on the other is not effective. A liquid should be added first and the powder next but apart from this the order has only a small effect (Aponbiede and Ochoukpa, 2008). Some foundries add the oil first, followed by the powder and after short interval water. Others add water first followed by the powder with oil last resulting in stronger cores. Other authors have been unable to detect any difference (Aponbiede and Ochoukpa, 2008).

Generally, bonding is achieved when binder and silica sand are mixed together by the attraction of electronegative charges of the elements that make up the binder to the

electropositive charges of the elements that make up the sand and vice versa. It is also generally held that like charges repel while unlike charges attract (Vlack, 1980).

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 MATERIALS

The following materials were used for this research.

Cissus populnea from Makurdi Local Government area of Benue state, Foundry Sand from Bacita, Kwara State, Water, Cassava Starch, Aluminium alloy Scraps, Grey cast iron Scraps sourced locally in Samaru.

3.2 EQUIPMENT

The following equipment was used for the research.

Core ramming machine by Ridsdale and Co. Ltd; Serial no 7319 , Baking oven by K.H. and Co, Model DR-OV Serial no DR 311, Universal Core strength testing machine by Ridsdale and Co. Ltd; Serial no LM-8415 , Core green compression tester by Ridsdale and Company ltd serial LM-8415, Assorted hand tools for making cores in the foundry, Crucible furnace, Mould boxes, Permeability meter Serial no 872, Moulding equipment, Graphite crucible pot, Molten metal handling equipment, Fettling equipment, Pestle and mortar, Bench mounted Sieve shaker by George Fisher serial no F-1673 type PSA, Precision weighing balance by Larks serial no LP50A , Dry milling machine, Energy Dispersion X Ray Fluorescence Spectrometry (ED-XRFS).

3.3 PROXIMATE ANALYSIS OF *CISSUS POPULNEA*

A comprehensive proximate analysis of *cissus populnea* was carried out at the Food Science Laboratory, Institute of Agricultural Research, Ahmadu Bello University Zaria.

The percentage composition of the lipids (fatty acids) in the plant was carried out at National Research Institute for Chemical Technology, Zaria.

3.4 METHODOLOGY

In carrying out the research, the following methods were adopted:

(i) Sieves were cleaned and placed according to their sieve number from higher to lower. 100g of silica sand was weighed and poured on the top sieve and was tightly closed. The machine was switched on and left to vibrate for 15 minutes. The weight of sand retained on each sieve was measured separately and recorded. The grain fineness number was calculated using the formula:

Grain fineness number = Product/Total weight retained.

(ii) 20g of sand sample was finely ground to pass through a 200-250 mesh sieve. The sample was dried in an oven at 105^0C and cooled. Thereafter, each of 5g was mixed with 1g cellulose flakes binder and pellitised at a pressure of 10-15 tons/cm^2 in a pelletising machine. The pelletised samples were stored in a dessicator for analysis. The ED-XRFS machine was switched on and allowed to warm up for 2 hours. Finally, appropriate programes for the various elements of interest were employed to analyse for their presence or absence.

(iii) Strands of *Cissus populnea* removed from the lug were dried under the sun to remove the moisture to the barest minimum. The dried specimen was grounded using a laboratory mill to obtain particle size of very fine powder that will pass through a sieve mesh of +200.

(iv) Silica sand from Bacita, Kwara State was used to prepare the specimens.

The specimens were prepared by measuring specific quantities of the sand, binder, water and starch. Each batch was mixed thoroughly as in a standard foundry laboratory.

The mix was then poured in the mould. This known mass was compacted with three blows weighing 6.5Kg each from a height of about 50mm from the rammer.

(v) The cores were baked at different temperatures ranging from160^{o}C to 200^{o}C for between 60 to 120 minutes varying the temperature at 20^{o}C and time at 30 minutes intervals. The baked cores were left to cool on the laboratory floor and thereafter transferred to desiccators for proper dehydration before testing.

(vi) The baked cores were tested for tensile strength using a universal core strength testing machine.

(vii) For permeability test, green compression strength and baked compression strength test, the core mixtures were prepared using a core mixer. The percentages of the total mix of 100% gave a total weight of the core mixture to be 680g. Using a sand rammer; standard test specimens of 50mmx50mm were made each weighing 155g.

The specimens for permeability were transferred to the permeability machine without removing them from the specimen tube. The specimen tube was then mounted on the electric permeter. The machine was switched on and the system lever moved to the test position. The permeability reading was then displayed on the dial of the machine.

The specimens for green compression strength after ramming for three times on the sand rammer were transferred to the universal strength testing machine. They were removed from the specimen tube and mounted on the universal strength testing machine using the compression strength accessory. The start button was

pressed and the specimen was failed in compression and the reading taken from the green compression strength scale.

The specimens for baked compression strength were removed from the specimen tube. They were transferred to the oven where some were baked at 160^0C for 1.5 hrs and the other at 180^0C for 1hr. They were then taken to the universal strength testing machine where the baked compression strength was determined using the dry compression strength scale.

(viii) For test castings cores were prepared using the above composition and the three baking temperatures of 160^0C for 1.5 hrs, 180^0C for 1hr and 200^0C for 1hr. A single cylindrical pattern with core print was used to mould. The gating system and the sprue were cut, the cope was closed and clamped tightly and the mould box was allowed to dry. Cast iron scraps from engine block were melted, treated with fluxes and then poured into the ladle. The melt was then poured into mould boxes and allowed to solidify before the shake and the castings removed. Some of the castings were sectioned to examine the structure of the castings.

Graphs were plotted using

(i) tensile strength against percentage of binder

(ii) tensile strength against water in binder

(iii) tensile strength against baking time

(iv) Tensile strength against baking temperature.

The graphs were interpreted to give

(i) highest binder concentration that developed the highest baked tensile strength

(ii) baking time that developed the highest baked tensile strength

(iii) baking temperature that developed the highest baked tensile strength

(iv) water content that developed the highest baked tensile strength

Cores were made using 5% and 7% binder concentrations and baked at temperatures: 160, 180, and 200^{o}C respectively in order to ascertain the best foundry properties of which baked tensile strength and permeability are most important (Jain, 2003). These cores were used in casting grey cast iron as well as Aluminium alloy. After cooling, the cores were collapsed to reveal the surface finish obtained.

3.5 DEVELOPMENT OF A STATISTICAL MODEL FOR CORE BINDING PROCESS

Factorial design and linear regression techniques have been widely used in engineering analysis. These consist of planning experiments in a precise way with the objective of acquiring data in a controlled way and executing these experiments in order to obtain information about the behaviour of a given process.

Two levels of each of the three main factors of baking temperature T_b, percentage weight of binder w_b and baking time t_b were used. The levels of these three factors are presented Table 3.1

Table3.1: Test - Factors for developing core strength

FACTORS	LOW LEVEL	HIGH LEVEL
Baking temperature (T_b)	160^0C	200^0C
Percentage weight of binder (w_b)	5%	7%
Baking time (t_b)	1 Hour	2 Hours

The treatment combinations for the two levels and the three factors are tabulated in Table 3.2

Table3.2: Factorial Design of *cissus populnea* as binder for core production showing the combinations of chosen factors.

Experiment number	Baking temperature (T_b)	Percentage weight of binder (w_b)	Baking time (t_b)
1	-1	-1	-1
T_b	+1	-1	-1
w_b	-1	+1	-1
T_b w_b	+1	+1	-1
t_b	-1	-1	+1
w_b t_b	-1	+1	+1
T_b t_b	+1	-1	+1
T_b w_b t_b	+1	+1	+1

3.5.1 Model for prediction of baked tensile strength of cores.

The model will be derived from the response functions of baking temperature, percentage weight of binder and baking time expressed as:

$X = f(T_b, w_b, t_b)$ ---------- (3.1)

$X = \beta_0 + \beta_1 T_b + \beta_2 w_b + \beta_3 T_b w_b + \beta_4 t_b + \beta_5 w_b t_b + \beta_6 T_b t_b + \beta_7 T_b w_b t_b$. ---------- (3.2)

Where X= the predicted baked tensile strength of cores,

β_0 = the intercept

β_1 to β_7 = the model coefficient for the input factor.

T_b = Baking temperature

w_b = Percentage weight of binder (*Cissus populnea*)

t_b = Baking time.

CHAPTER 4

RESULTS

4.1 SIEVE ANALYSIS AND CHEMICAL COMPOSITION OF BACITA SAND

The results of sieve analysis and chemical composition of Bacita sand are presented in Appendix A1 and A2 respectively.

4.2 BAKED TENSILE STRENGTH VALUES OF CORE SAMPLES

The main results are presented in two folds. The first is tensile strength values Tables B1 to B15 (Appendix B).

4.3 OTHER TESTED PARAMETERS OF CORE SAMPLES CONTAINING 7% *CISSUS POPULNEA* AS BINDER

The Appendix C1 and C2 contain some tables which display some excellent values of moulding mixtures such as 7% binder.

4.4 CHEMICAL COMPOSITION OF *CISSUS POPULNEA* AND ITS LIPIDS (FATTY ACIDS)

Table D1 shows the chemical composition of *cissus populnea* and Table D2 shows the composition of the lipids (fatty acids) in the plant.

4.5 GRAPHS OF PHYSICAL PARAMETERS OF CORE SAMPLES

The second results contains series of graphical representations of effect of baked strength property of 3, 4, 5, 6, and 7% *cissus populnea* and 0.5% cassava starch in each case with water content 4, 5, 6, 7, and 8% displayed at temperatures 160, 180 and 200^0C for baking time of 1 to 2 hours Figures 4.1 to 4.15. Similarly Figures 4.16 to 4.30 show the graphs of effect of baked strength property of 4,5 6 and 7% *cissus populnea* at baked temperature of 160, 180, and 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

Figures 4.31 to 4.45. show the graphs of effect of baked strength property of 3, 4, 5, 6, and 7% *cissus populnea* and 0.5% Cassava starch, 4, 5, 6, 7 and 8% water baked at a temperature of 160, 180, and 200^0C and baking time of 1, 1.5 and 2 hours. Figure 4.46 show the optimum baked strength property developed at 7% *cissus populnea* 0.5% cassava starch baked at a temperature of 160, 180 and 200^0C, baking time of 1-2 hours.

In all these processes, a fixed value of cassava starch 0.5% was used to impact green strength.

4.6 STATISTICAL DESIGN FOR PREDICTING BAKED STRENGTH OF CORE SAMPLES

Table D1 shows complete matrix including interactions with effect calculated. Table D2 shows the analysis of variance to identify factors influencing baked tensile strength of cores. Table D3 shows the comparison of the actual baked tensile strength with the predicted values. Figure 4.46 shows the graph of optimum baked strength property developed at 7% *cissus populnea,* 0.5% cassava starch baked at a temperature of 160, 180 and 200^0C, baking time of 1-2hours. Figure 4.47 shows the bar chart of actual and predicted baked tensile strength values.

4.7 SAMPLES OF CAST MATERIALS WHOSE CORES ARE MADE OF 5% AND 7% *CISSUS POPULNEA*

Plate BI shows the as-cast surface finish of aluminium alloy casting utilizing 5% *cissus populnea* as binder for both mould and core production. Plate BII shows the as-cast

surface of aluminium alloy castings whose moulds as well as cores were from a binder containing 5% *cissus populnea* and baked at 160^0C for 1 hour.

Plate BIII shows the as-cast surface finish of both the internal as well as the external walls of two aluminium alloy castings whose moulds as well as cores were made from a binder containing 5% *cissus populnea* as binder.

Plate BIV shows the as-cast internal surface of grey iron casting utilizing a core made from 7% binder and baked at 160^0C at a baking time of 1.5hours.

Plate BV shows the sectioned as-cast internal surface of grey iron casting utilizing a core made from 7% binder and baked at 180^0C at a baking time of 1hour.

Plate BVI shows the as-cast internal surface of grey iron casting utilizing a core made from 7% binder and baked at 200^0C at a baking time of 1hour.

4.8 COMPARISM OF BAKED TENSILE STRENGTH OF 7% *CISSUS POPULNEA* WITH OTHER VALUES DEVELOPED USING OTHER LOCAL BINDERS BY OTHER RESEARCHERS

Table D1 shows in summary form baked tensile strength and in some cases baked compressive strength developed by various binders by various researchers including the one developed in this research work.

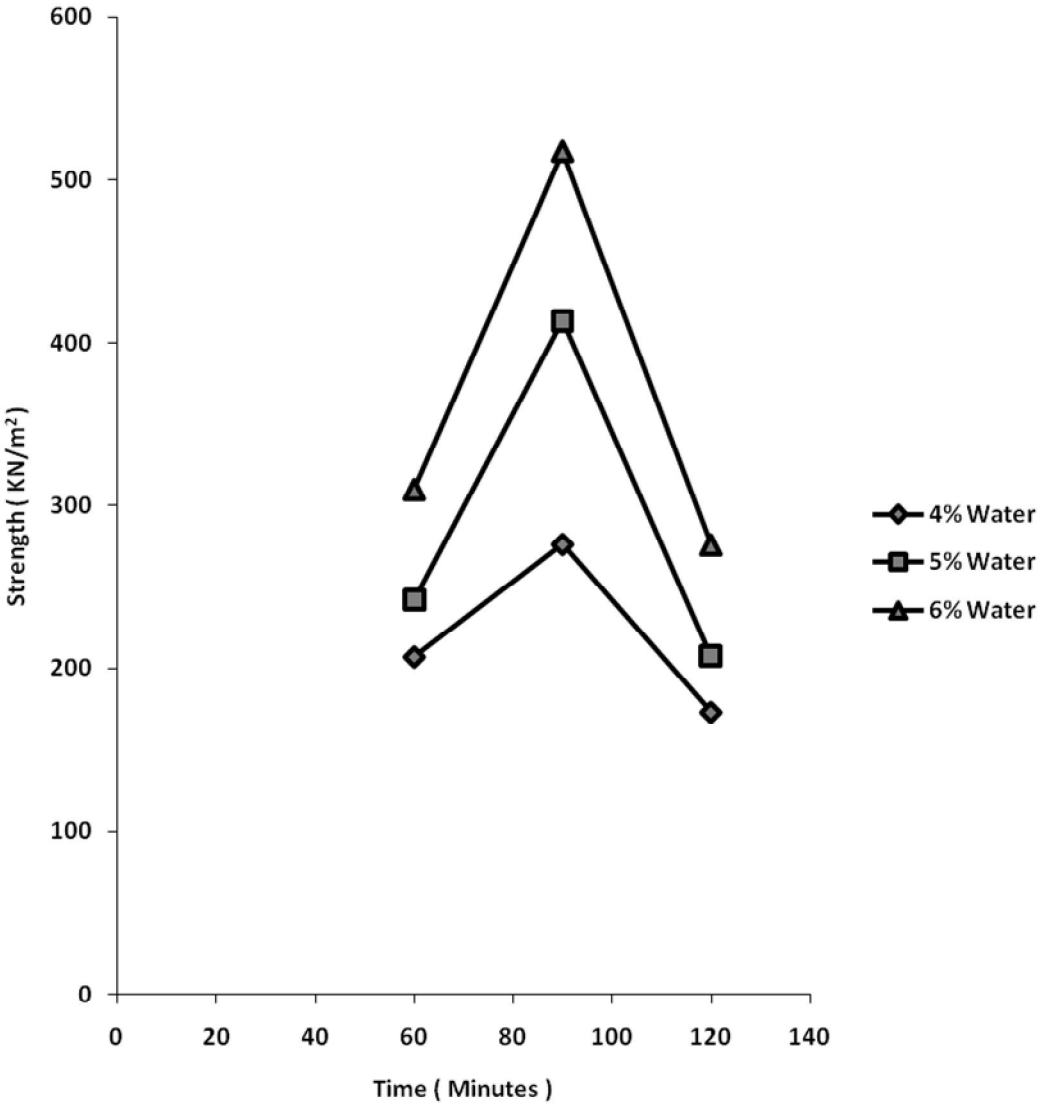


Figure 4.1: Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch with water content of 4 ,5 and 6% at baked temperature of 160^0C for baking time of 1 -2 hours.

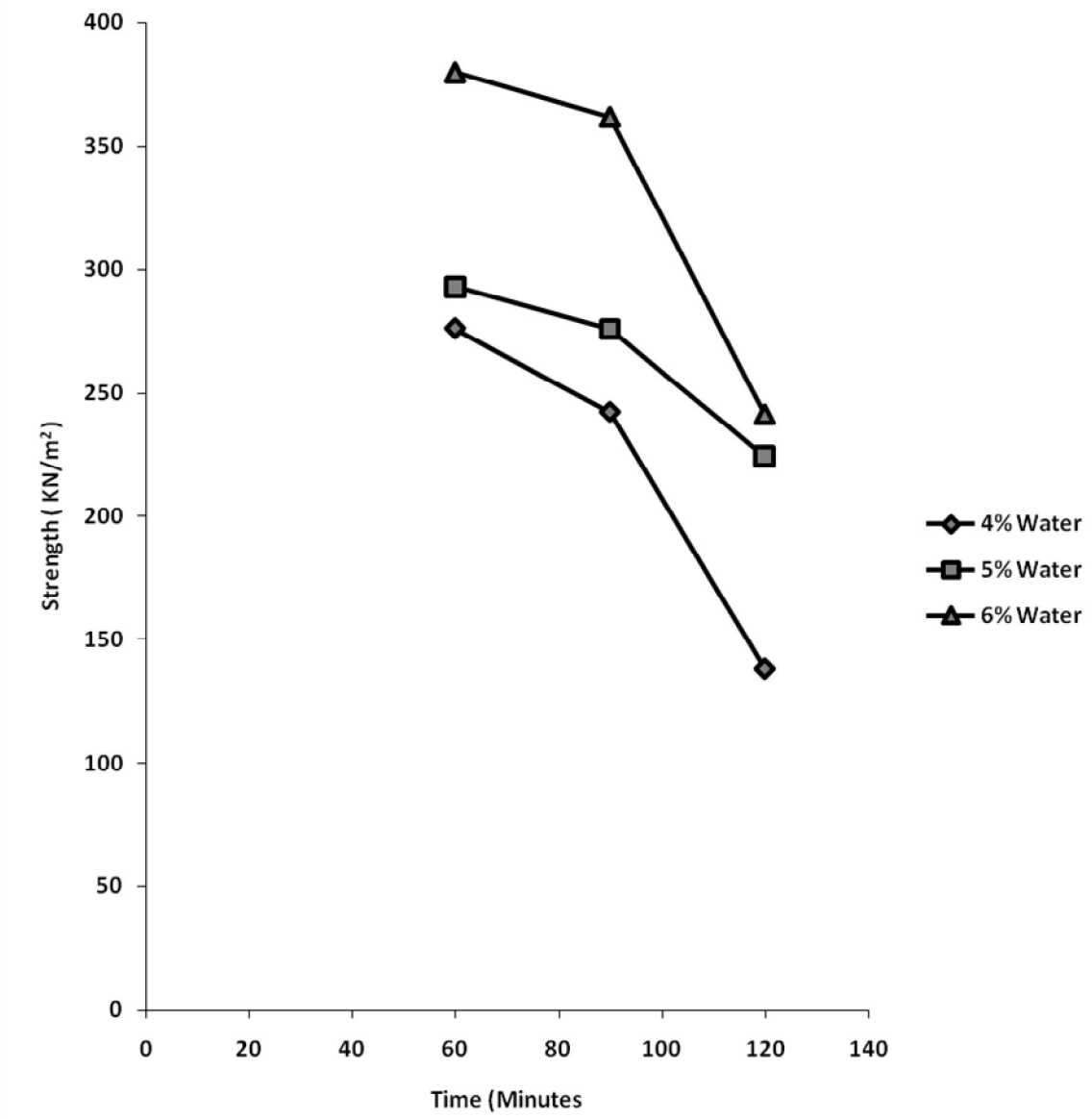


Figure 4.2: Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5 and 6% at baked temperature of 180^0C for baking time of 1 -2 hours.

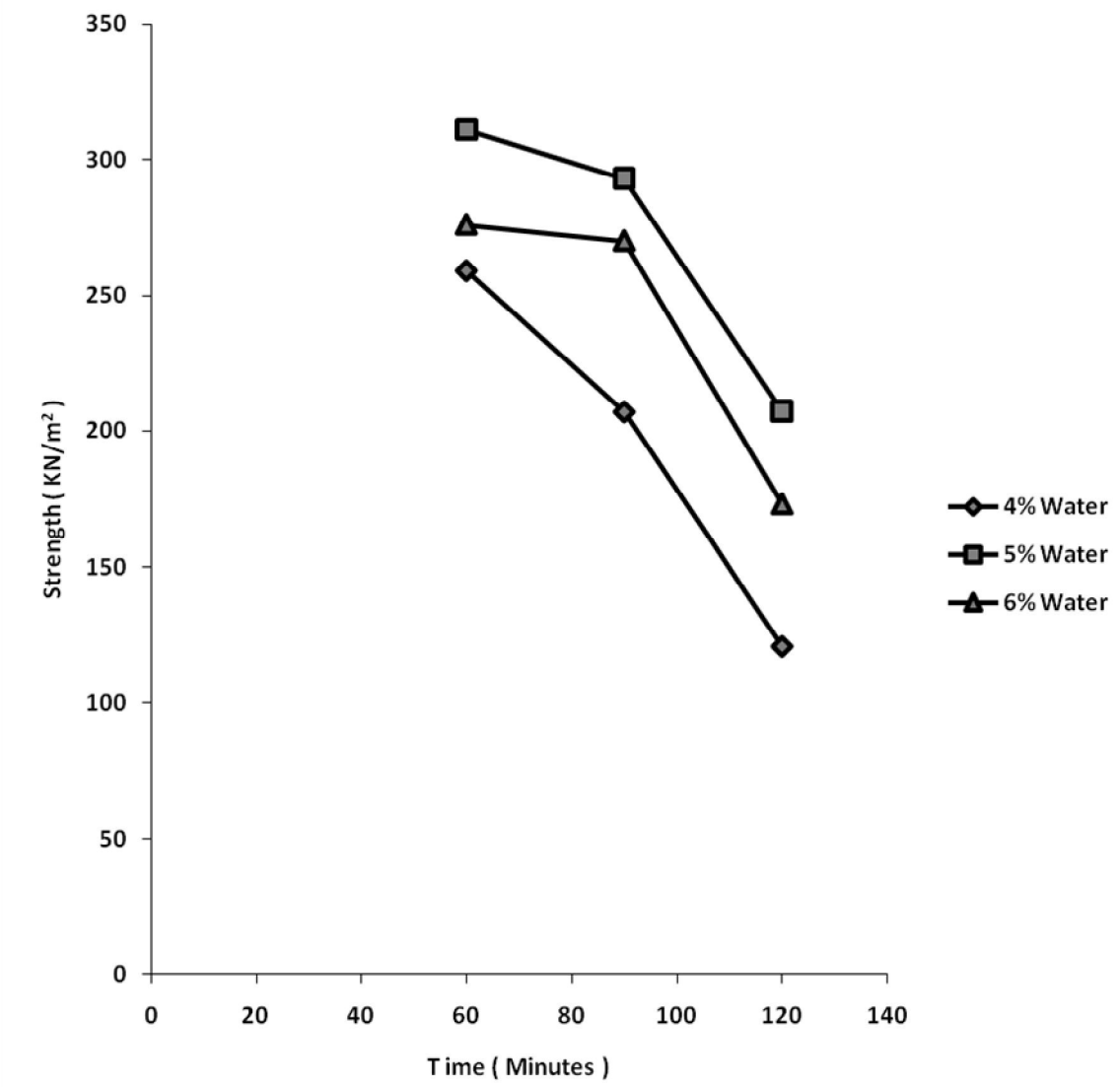


Figure 4.3: Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5 and 6% at baked temperature of 200^0C for baking time of 1 -2 hours.

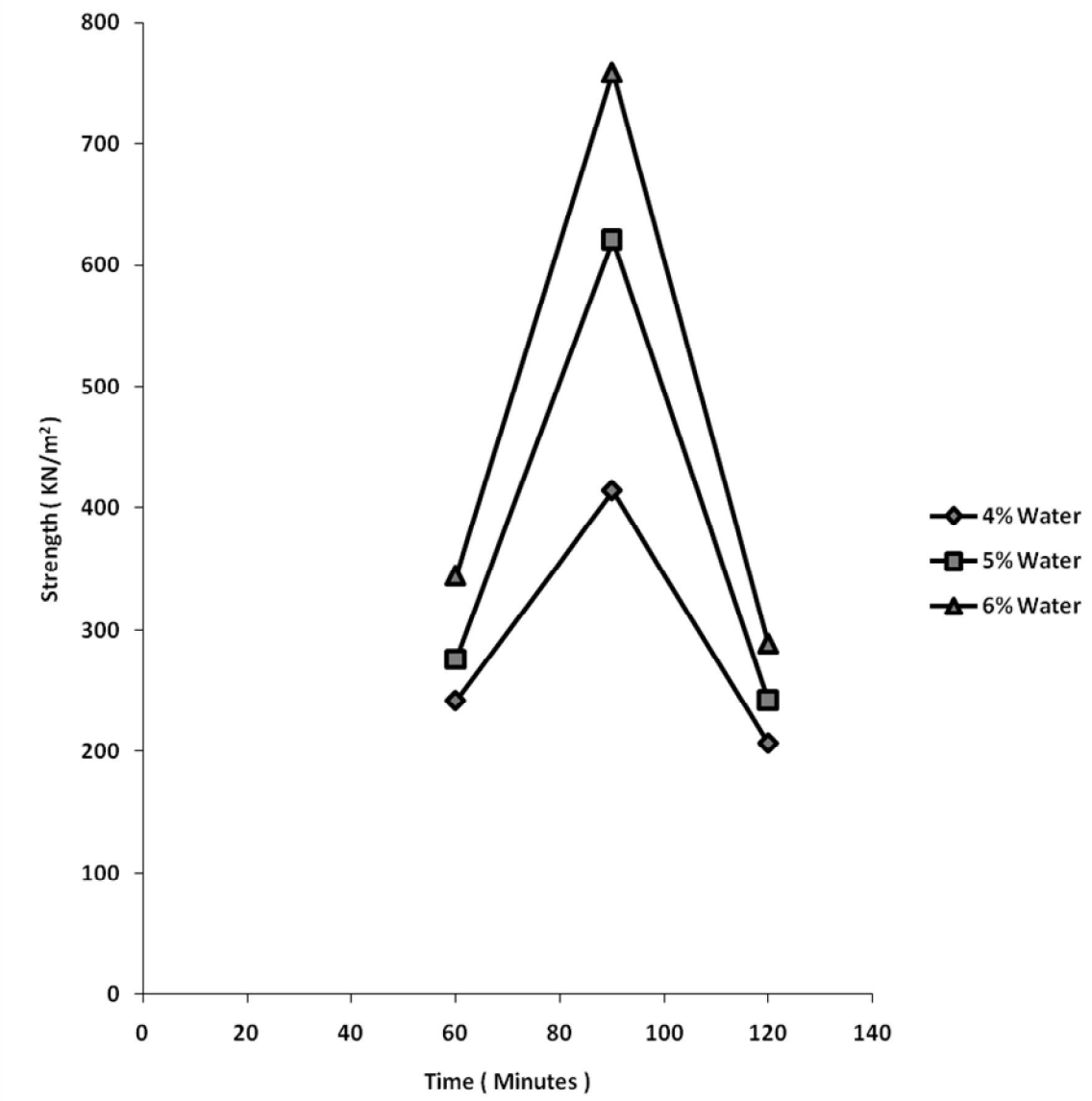


Figure 4.4: Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5 and 6% at baked temperature of 160^0C for baking time of 1 -2 hours.

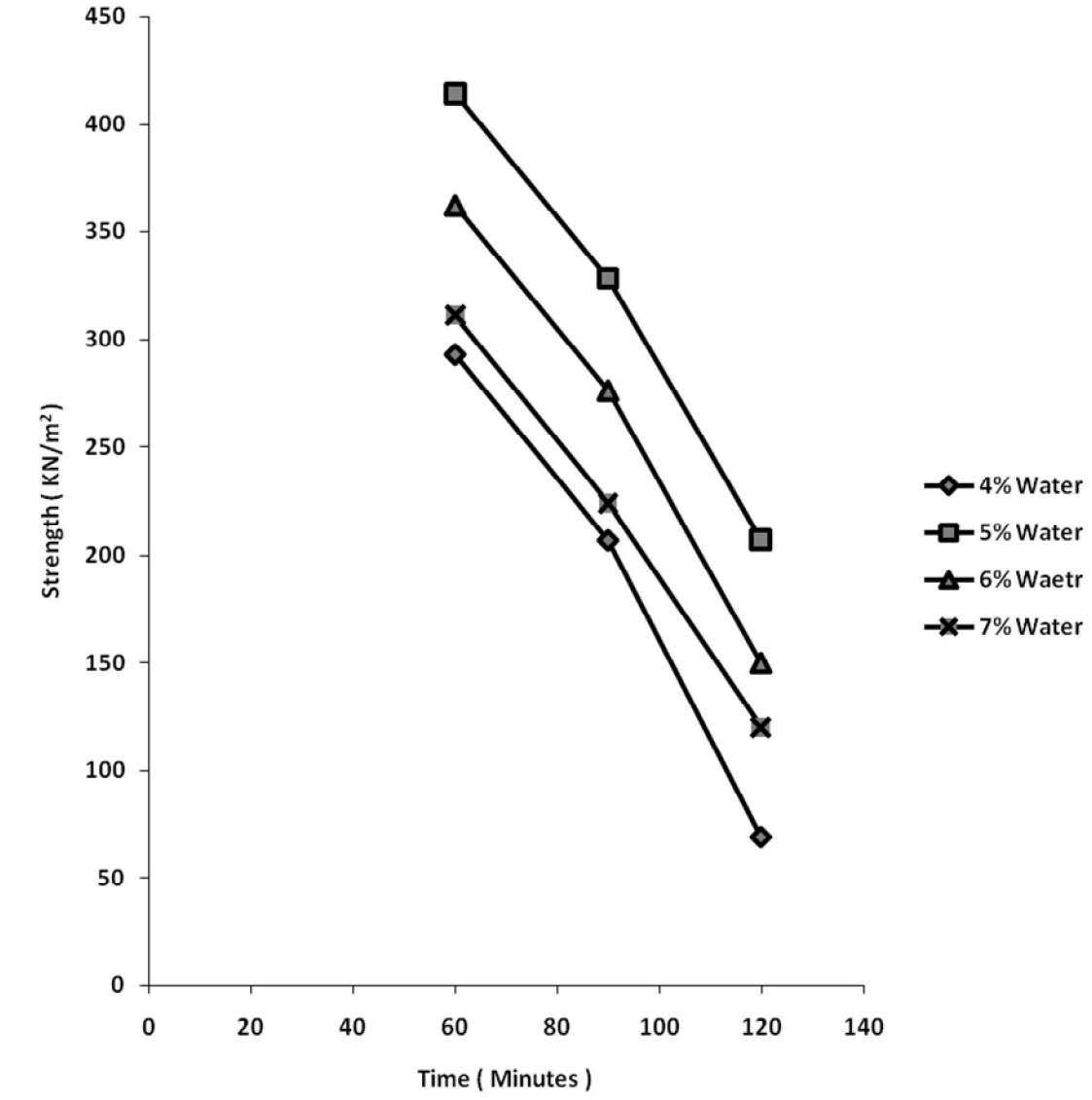


Figure 4.5: Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5, 6 and 7% at baked temperature of 180^0C for baking time of 1 -2 hours.

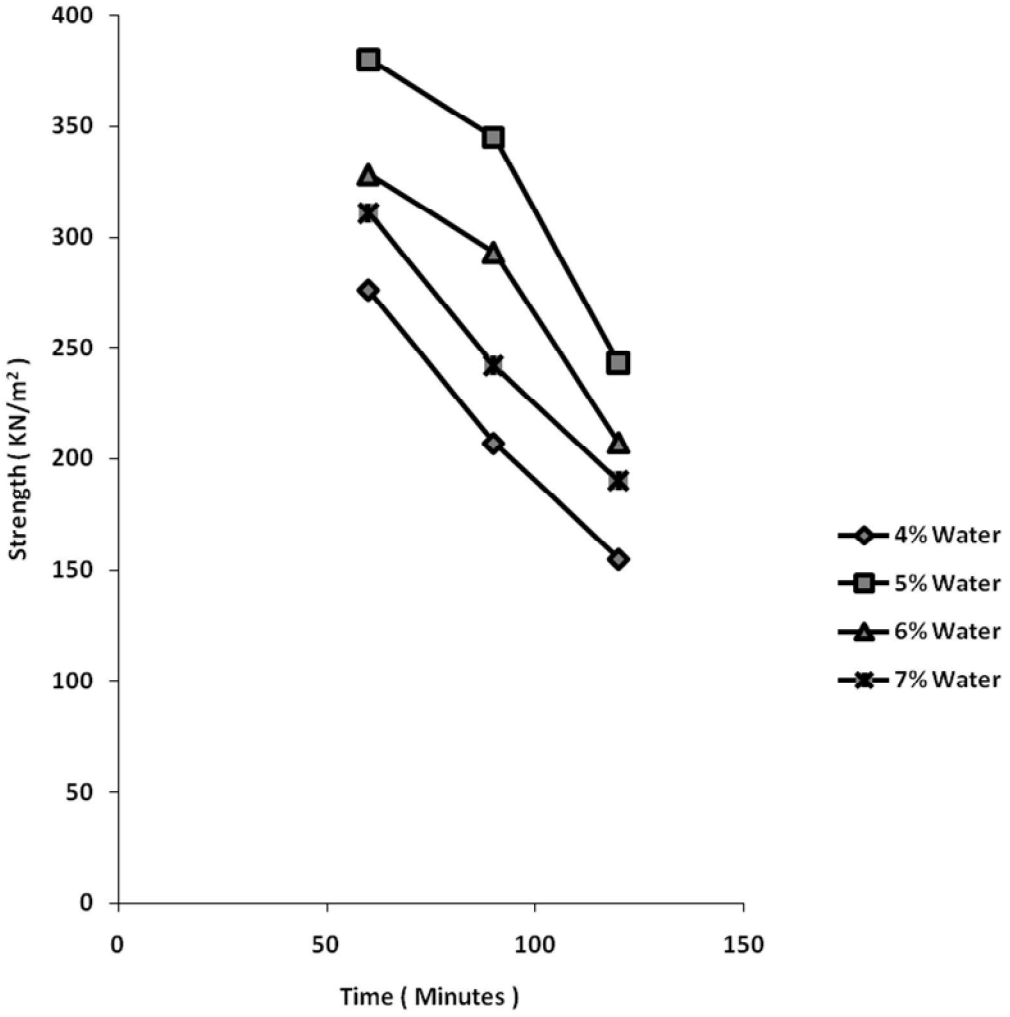


Figure 4.6: Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5, 6 and 7% at baked temperature of 200^0C for baking time of 1 -2 hours.

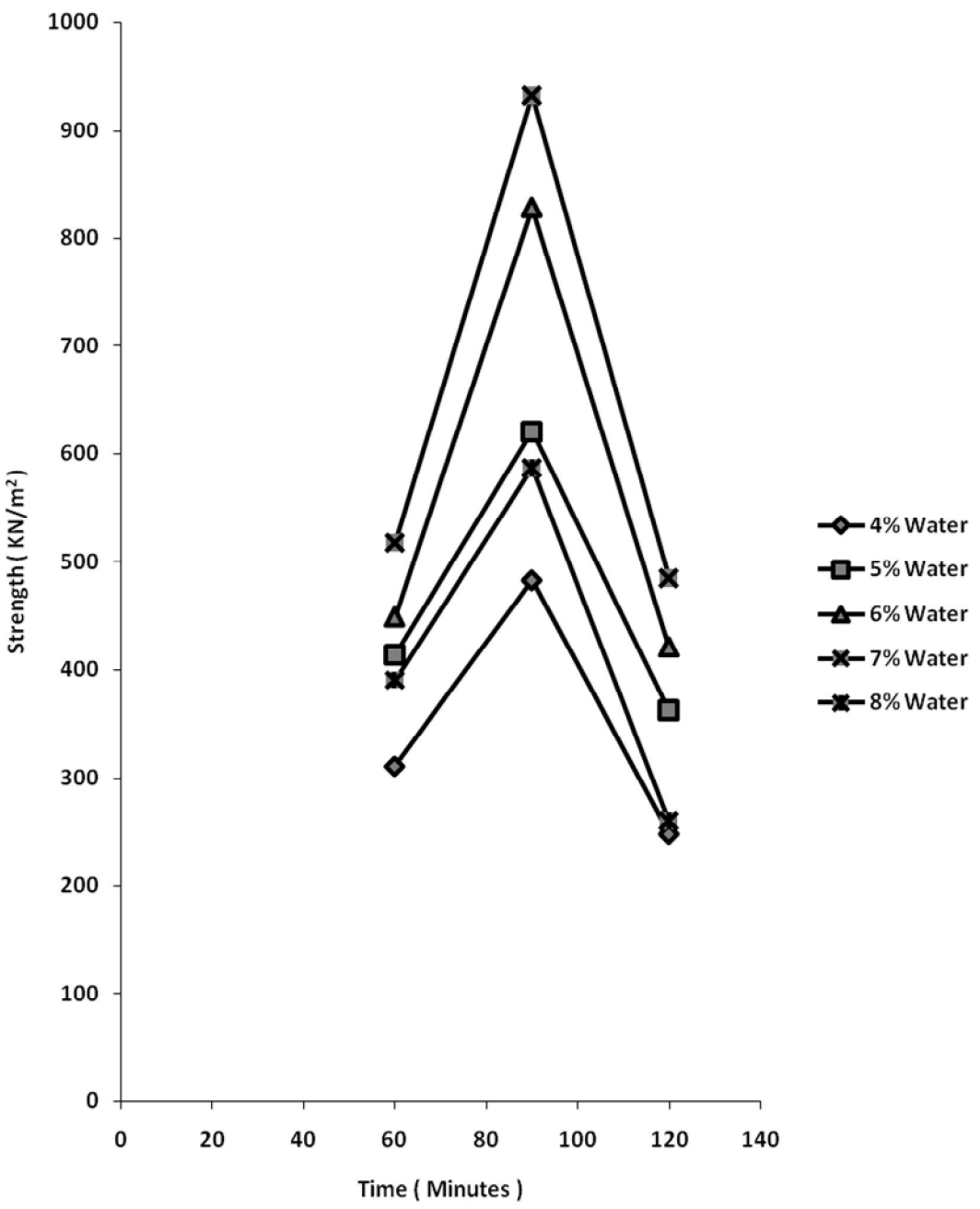


Figure 4.7: Effect of baked strength property of 5% *cissus populnea* and 0.5% cassava starch with water content of 4 – 8% at baked temperature of 160^0C for baking time of 1 -2 hours.

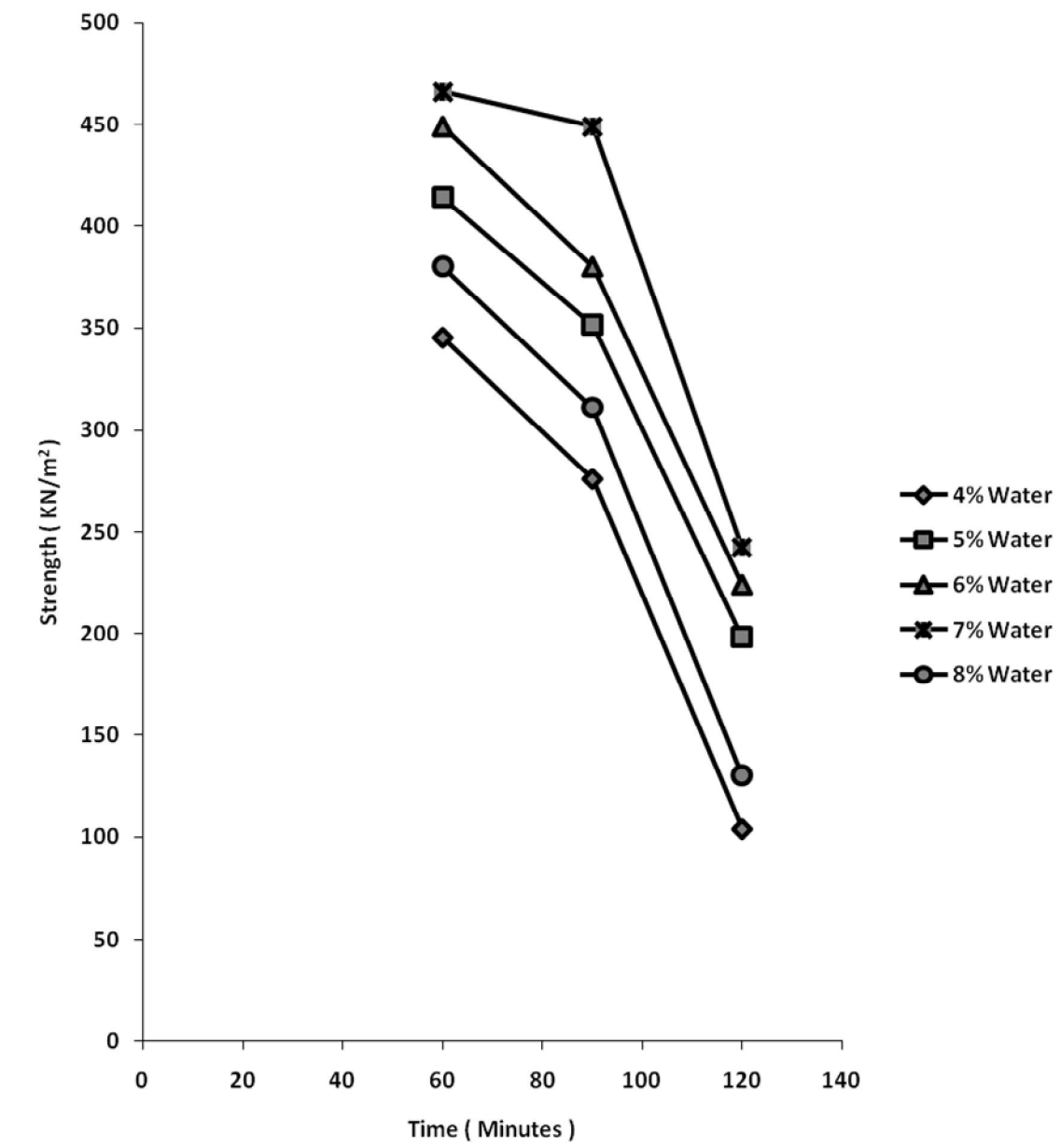


Figure 4.8: Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5, 6, 7 and 8% at baked temperature of 180^0C for baking time of 1 -2 hours.

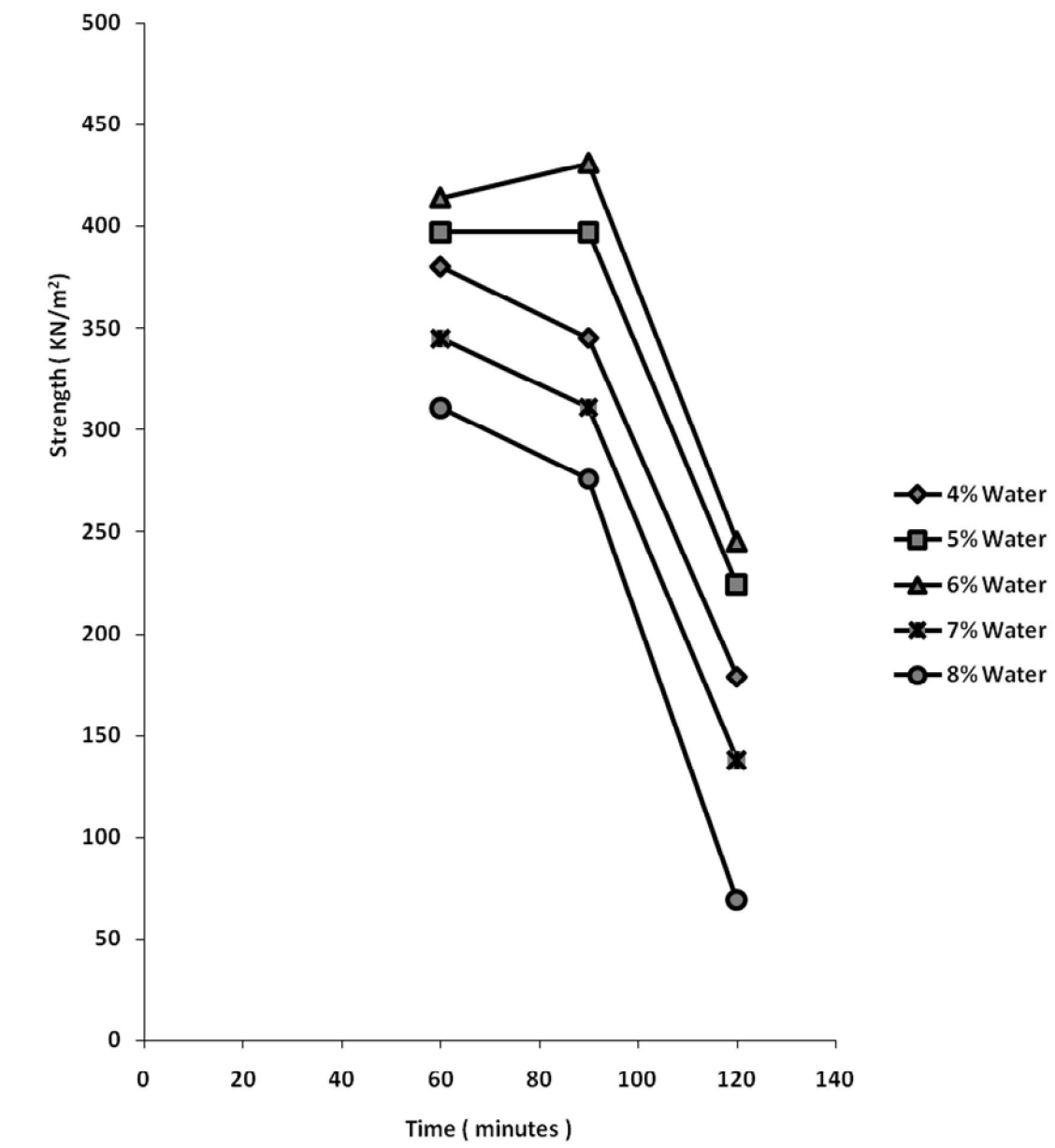


Figure 4.9: Effect of baked strength property of 4% *cissus populnea* and 0.5% cassava starch with water content of 4 ,5, 6, 7 and 8% at baked temperature of 200^0C for baking time of 1 -2 hours.

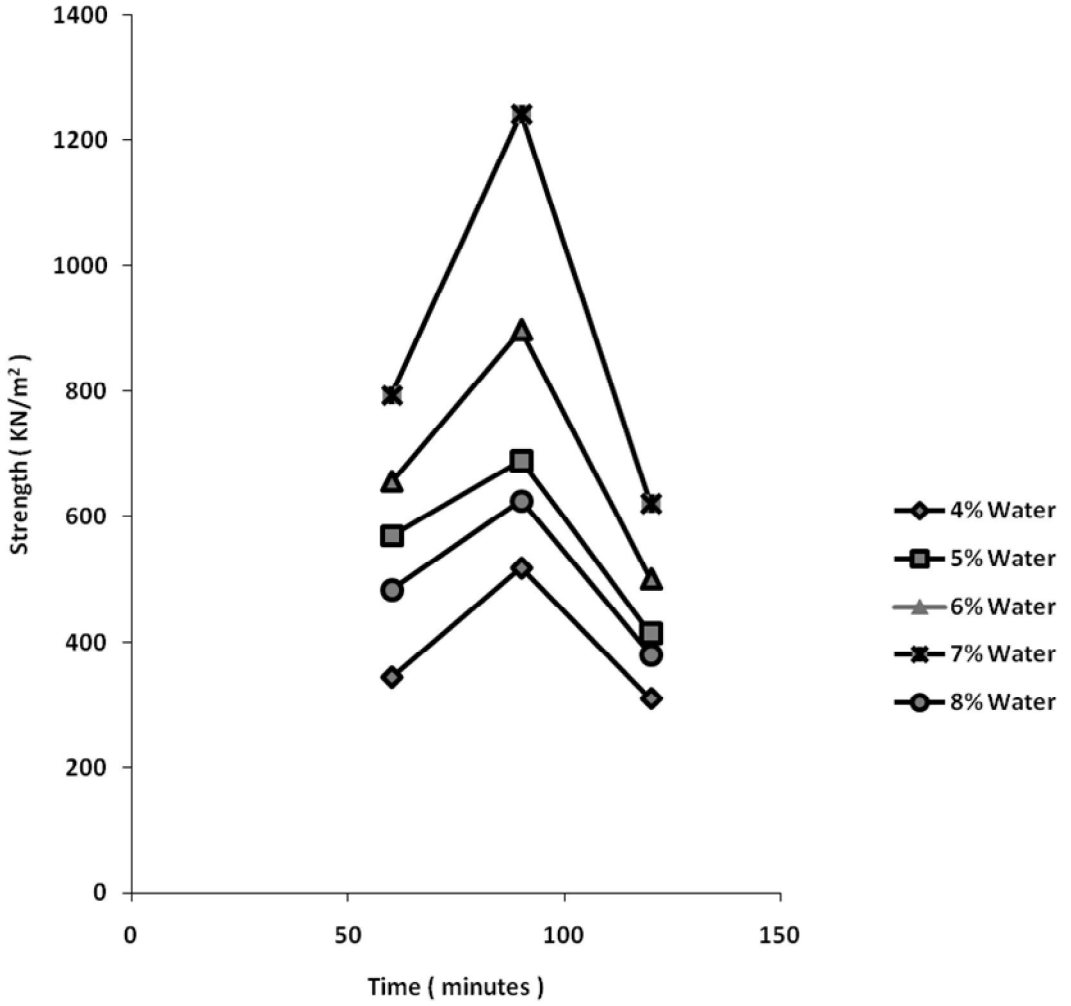


Figure 4.10: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4,5,6,7 and 8% at baked temperature of 160^0C for baking time of 1 -2 hours.

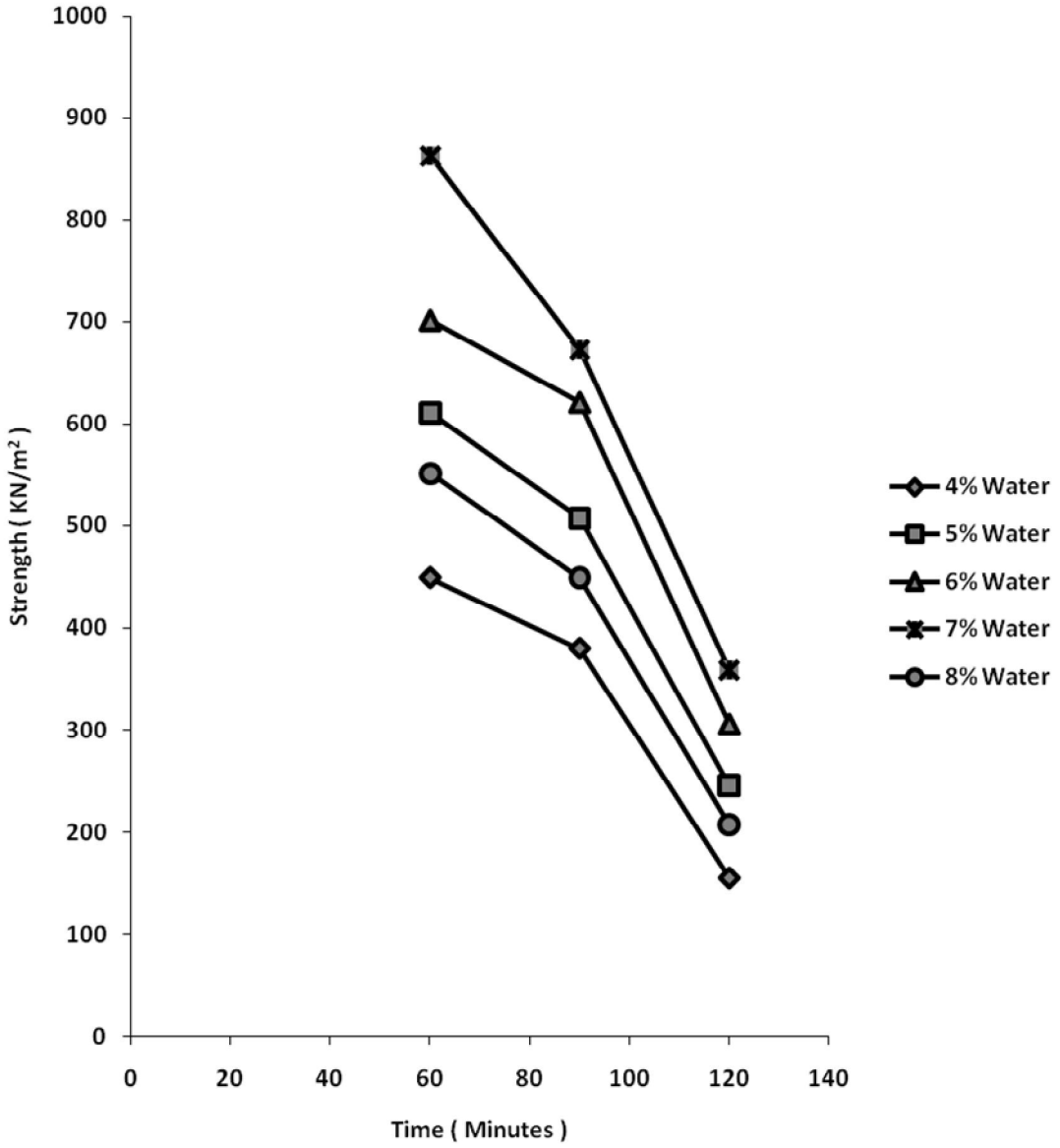


Figure 4.11: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4,5,6,7 and 8% at baked temperature of 180^0C for baking time of 1 -2 hours.

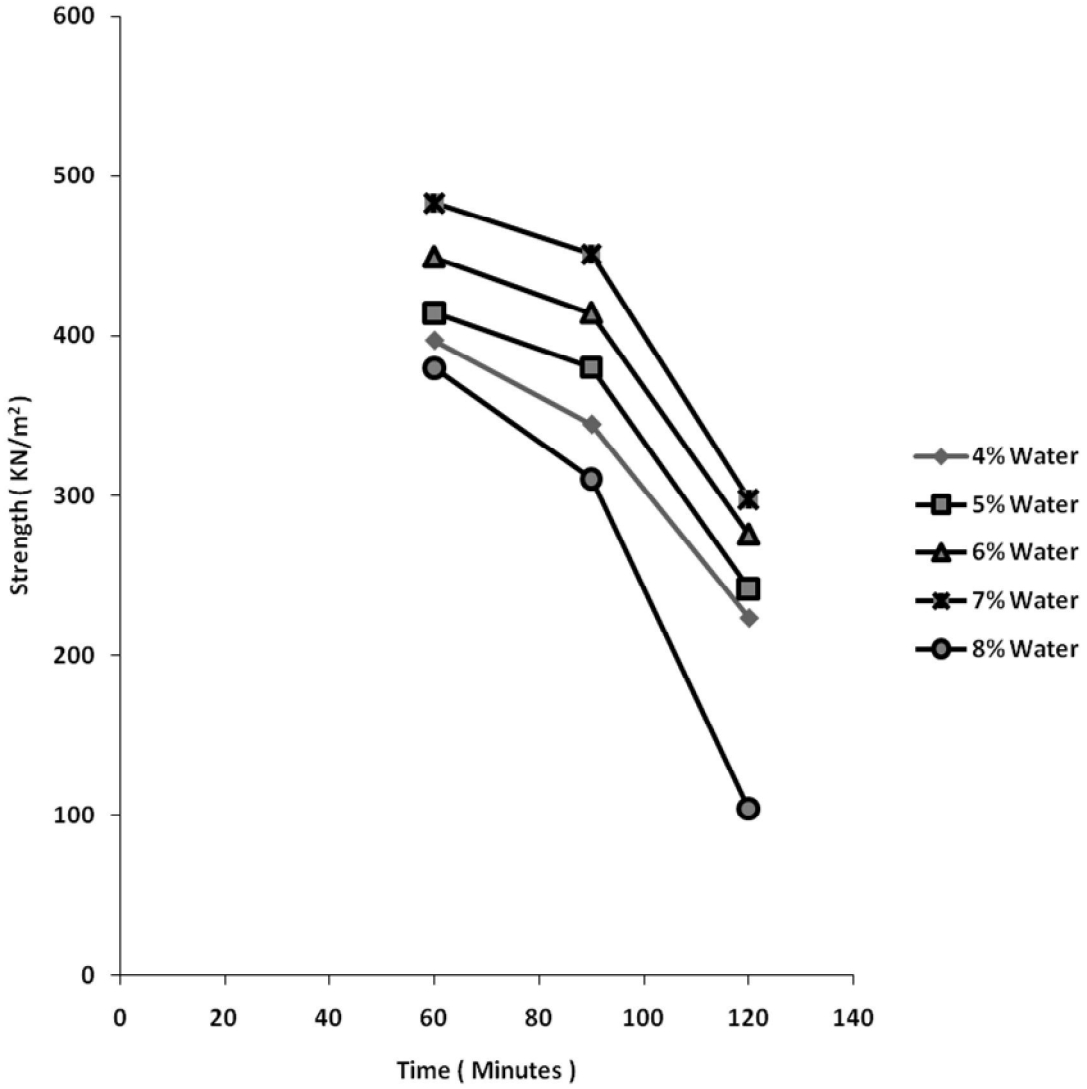


Figure 4.12: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch with water content of 4,5,6, 7 and 8% at baked temperature of 200^0C for baking time of 1 -2 hours.

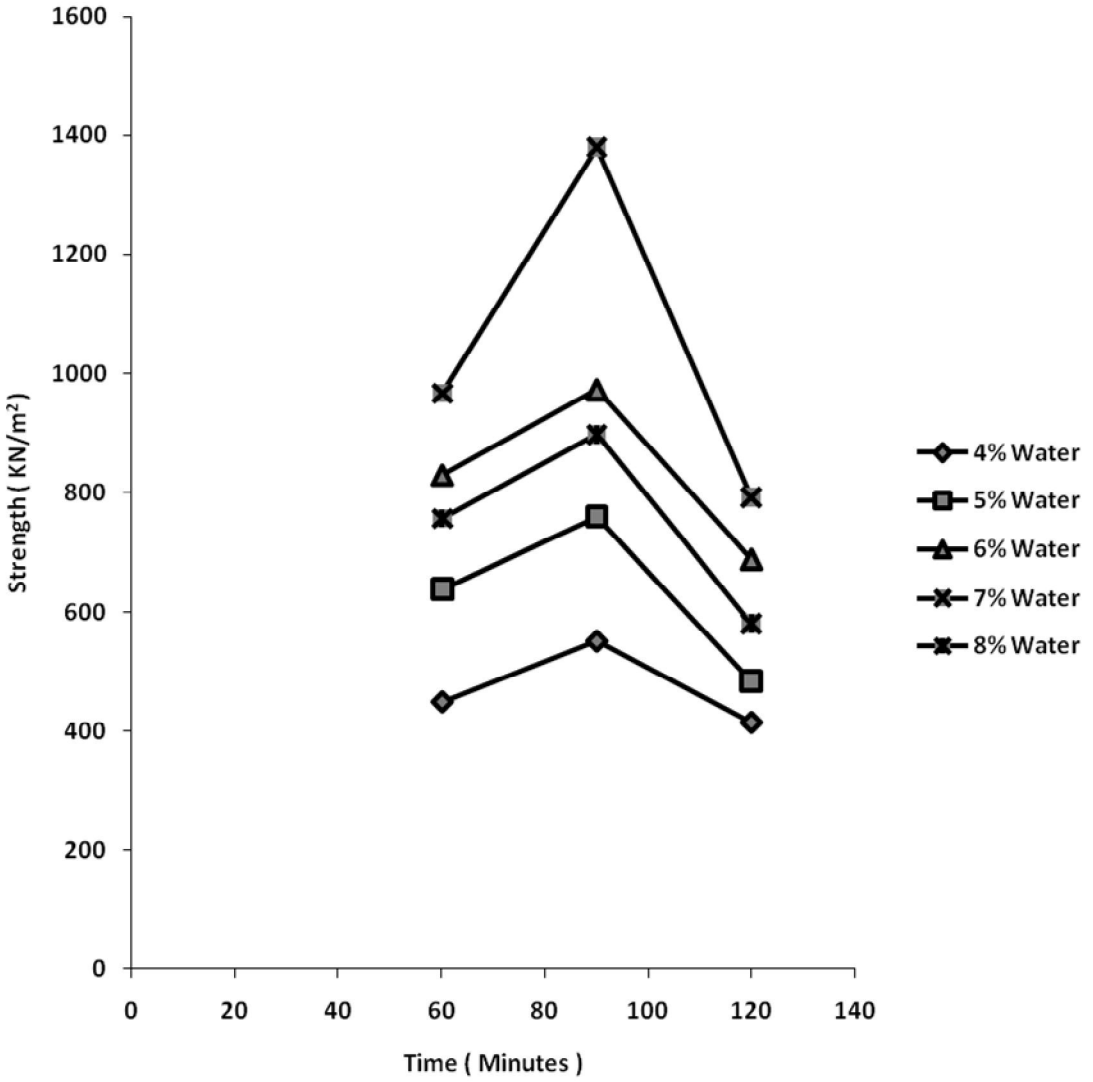


Figure 4.13: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 160^0C for baking time of 1 -2 hours.

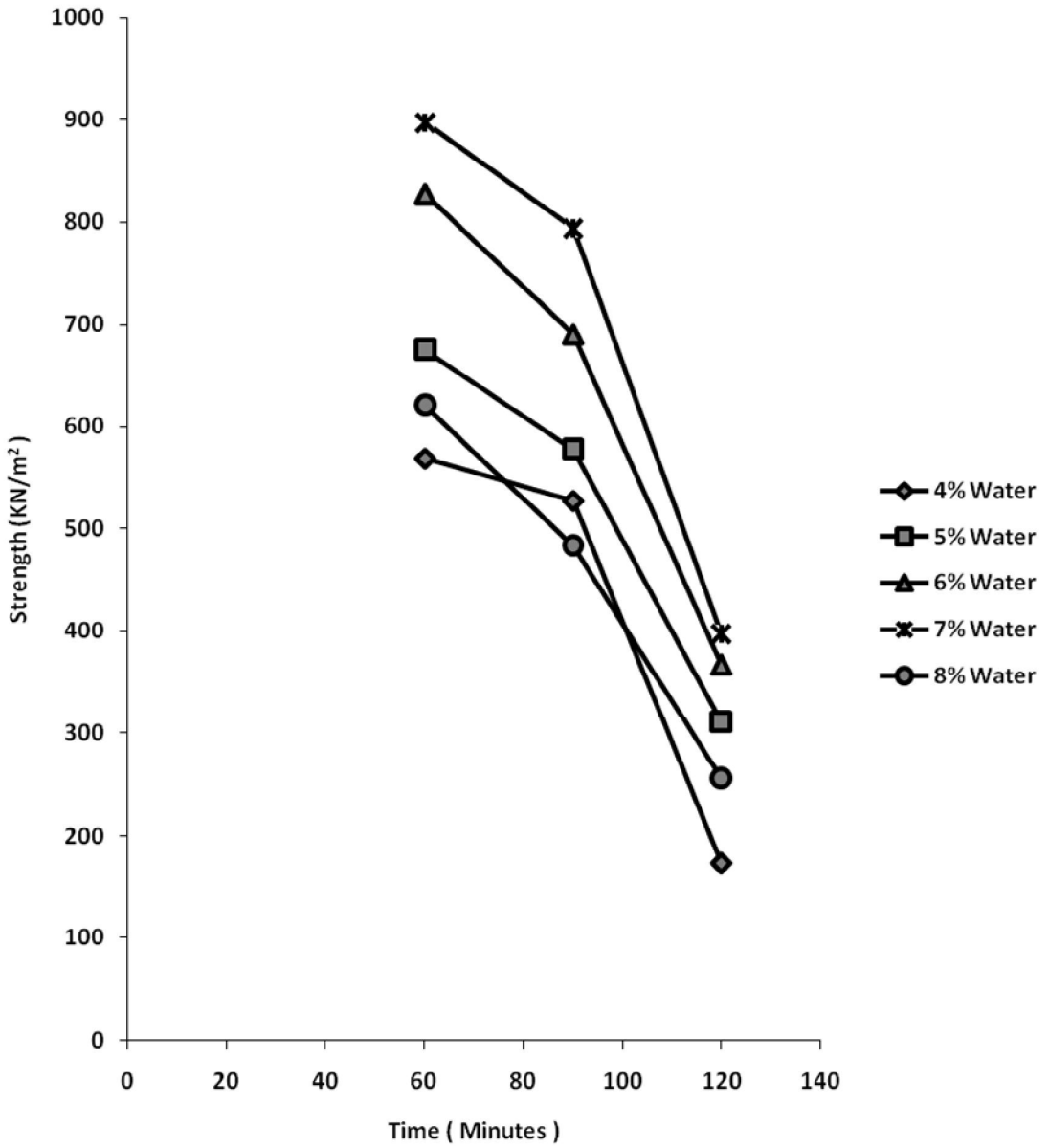


Figure 4.14: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 180^0C for baking time of 1 -2 hours.

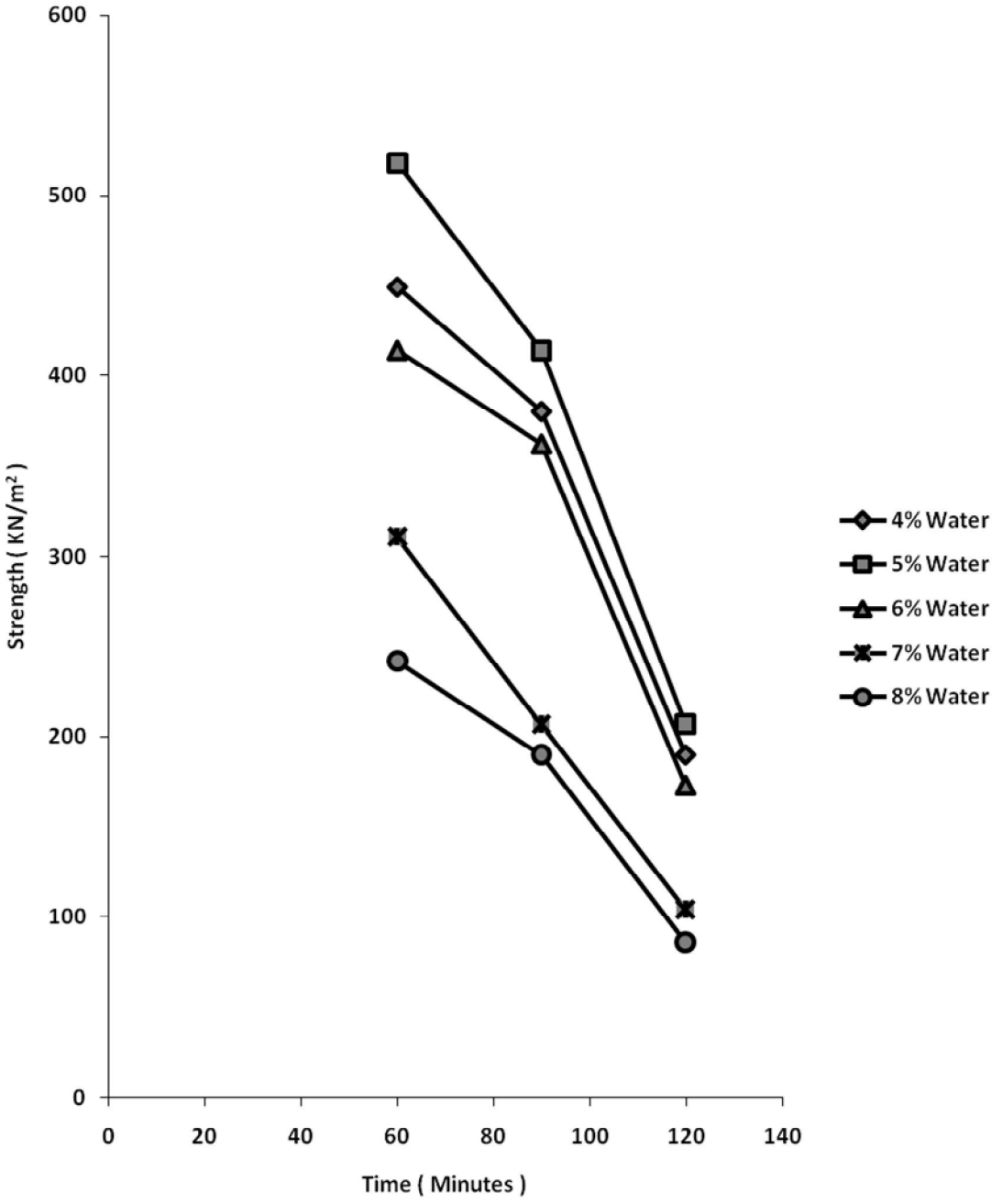


Figure 4.15: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch with water content of 4, 5, 6, 7 and 8% at baked temperature of 200^0C for baking time of 1 -2 hours.

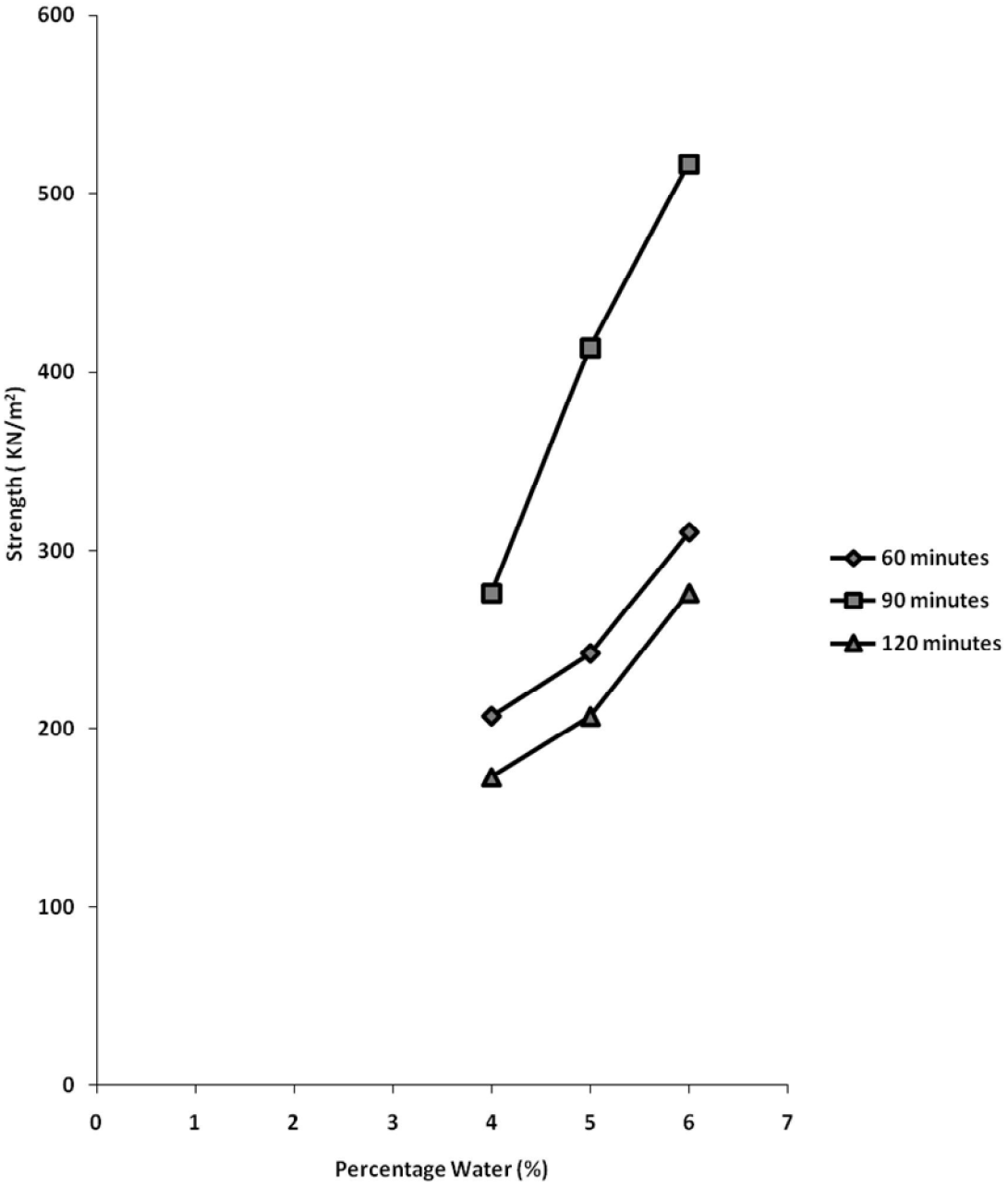


Figure 4.16: Effect of baked strength property of 3% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content.

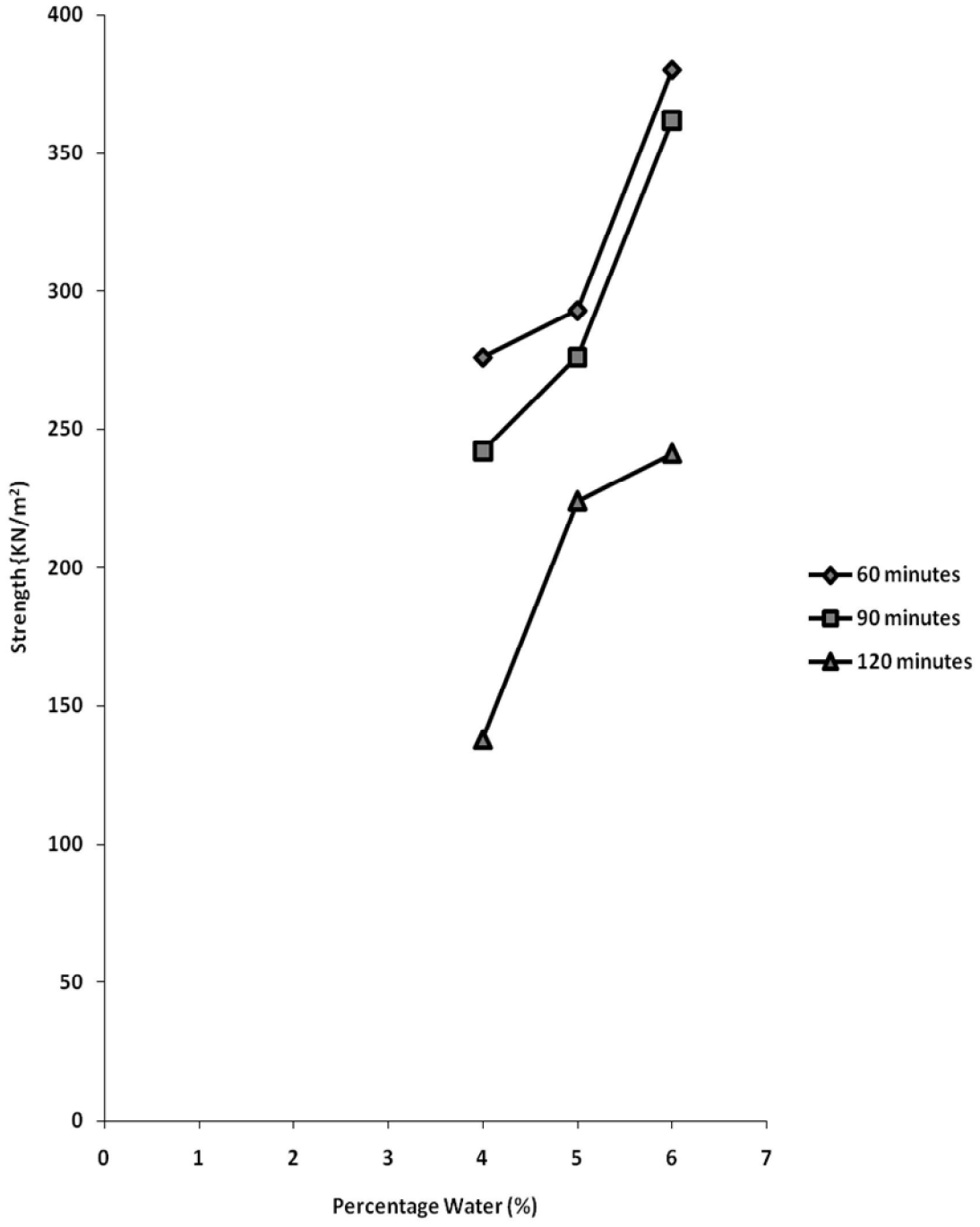


Figure 4.17: Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content.

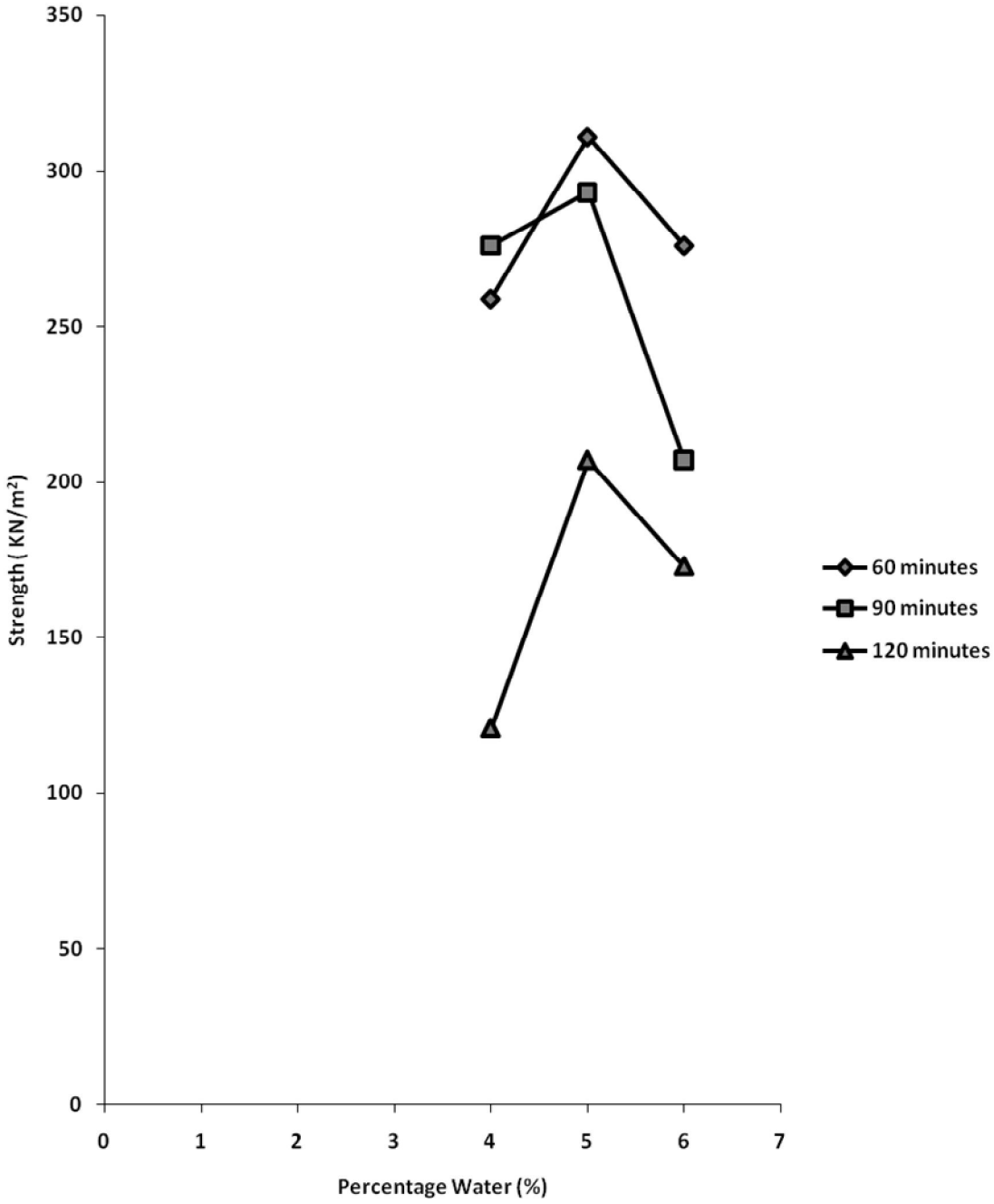


Figure 4.18: Effect of baked strength property of 3% *cissus populnea* and 0.5% cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content.

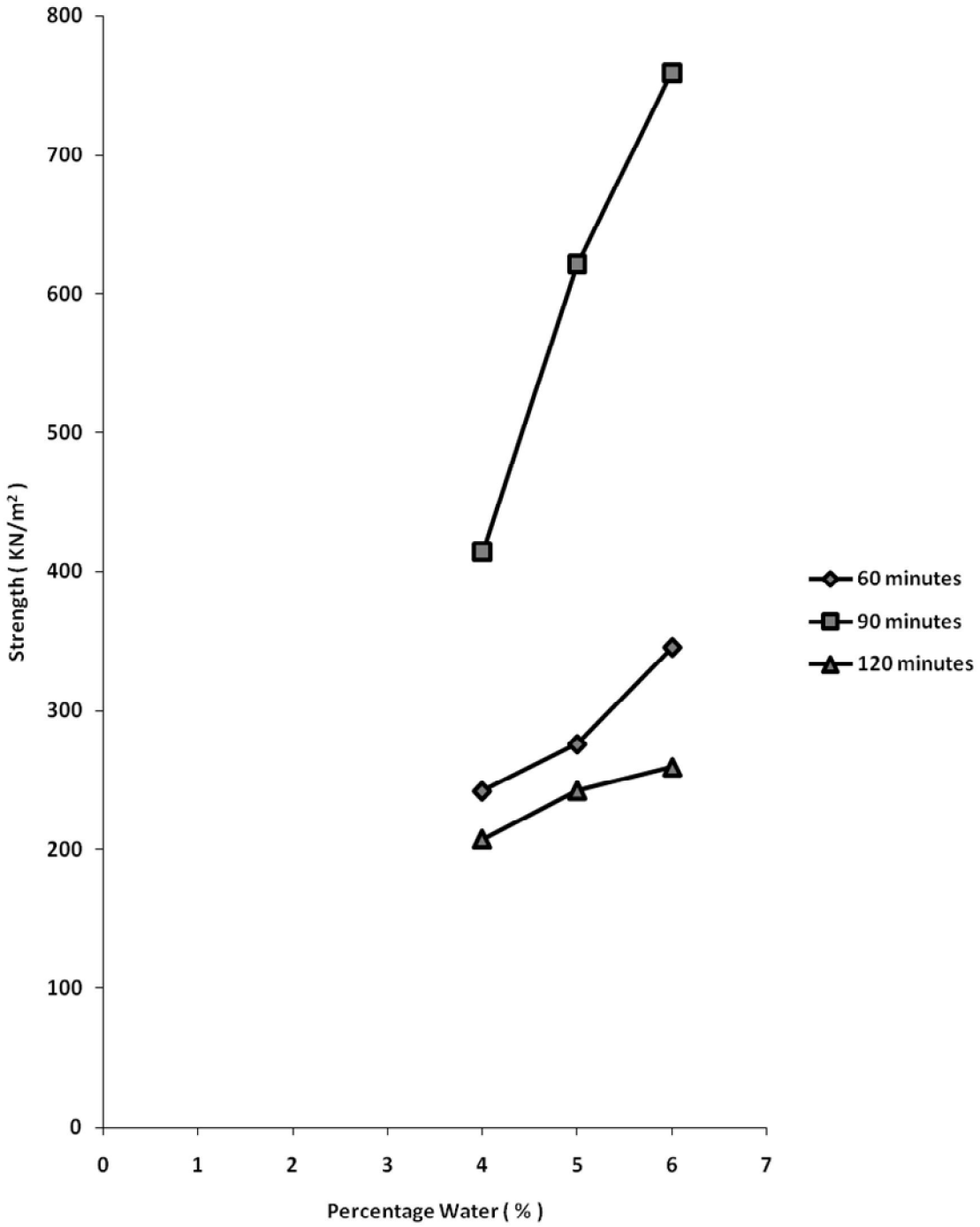


Figure 4.19: Effect of baked strength property of 4% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 6% water content.

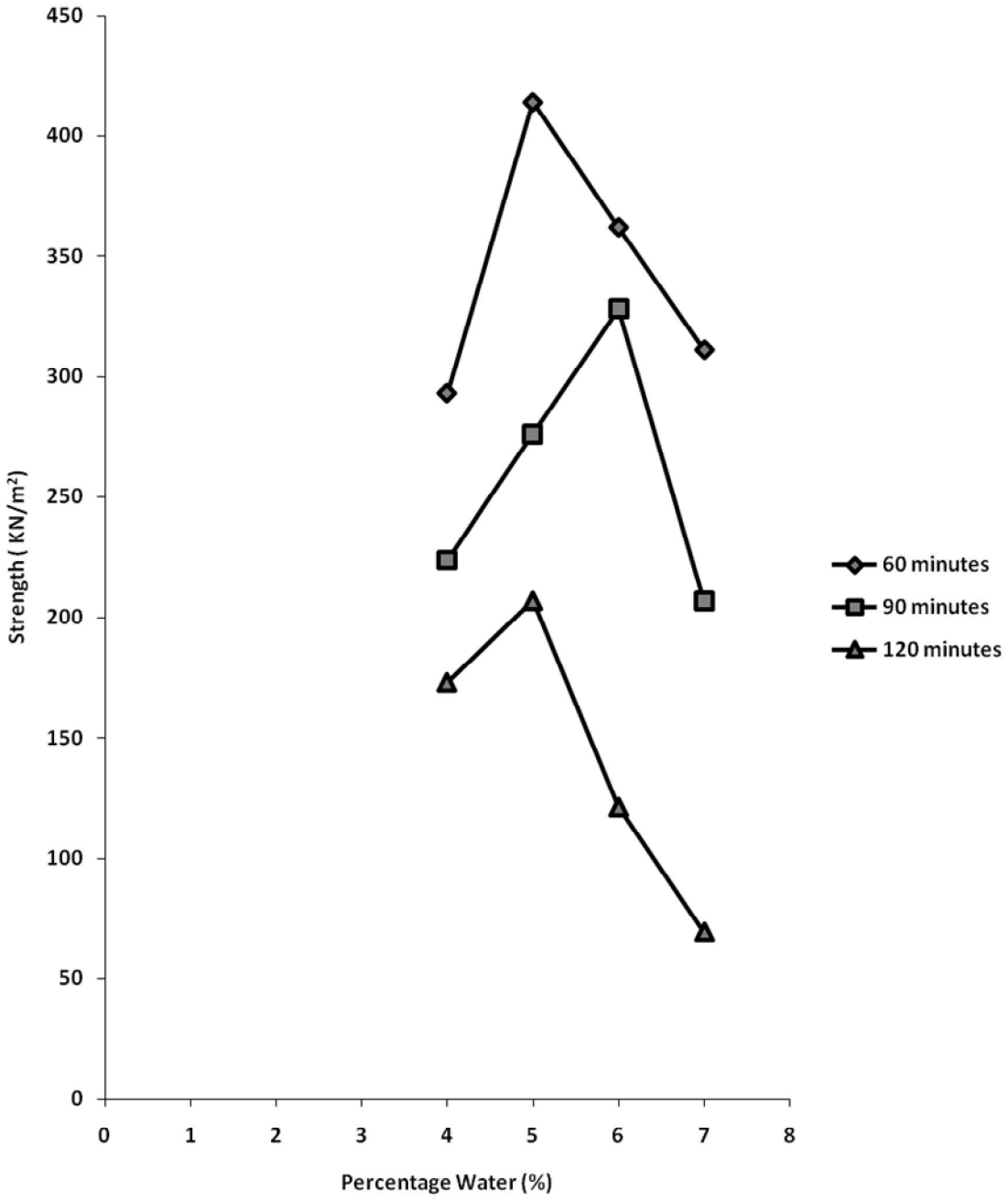


Figure 4.20: Effect of baked strength property of 4% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 7% water content.

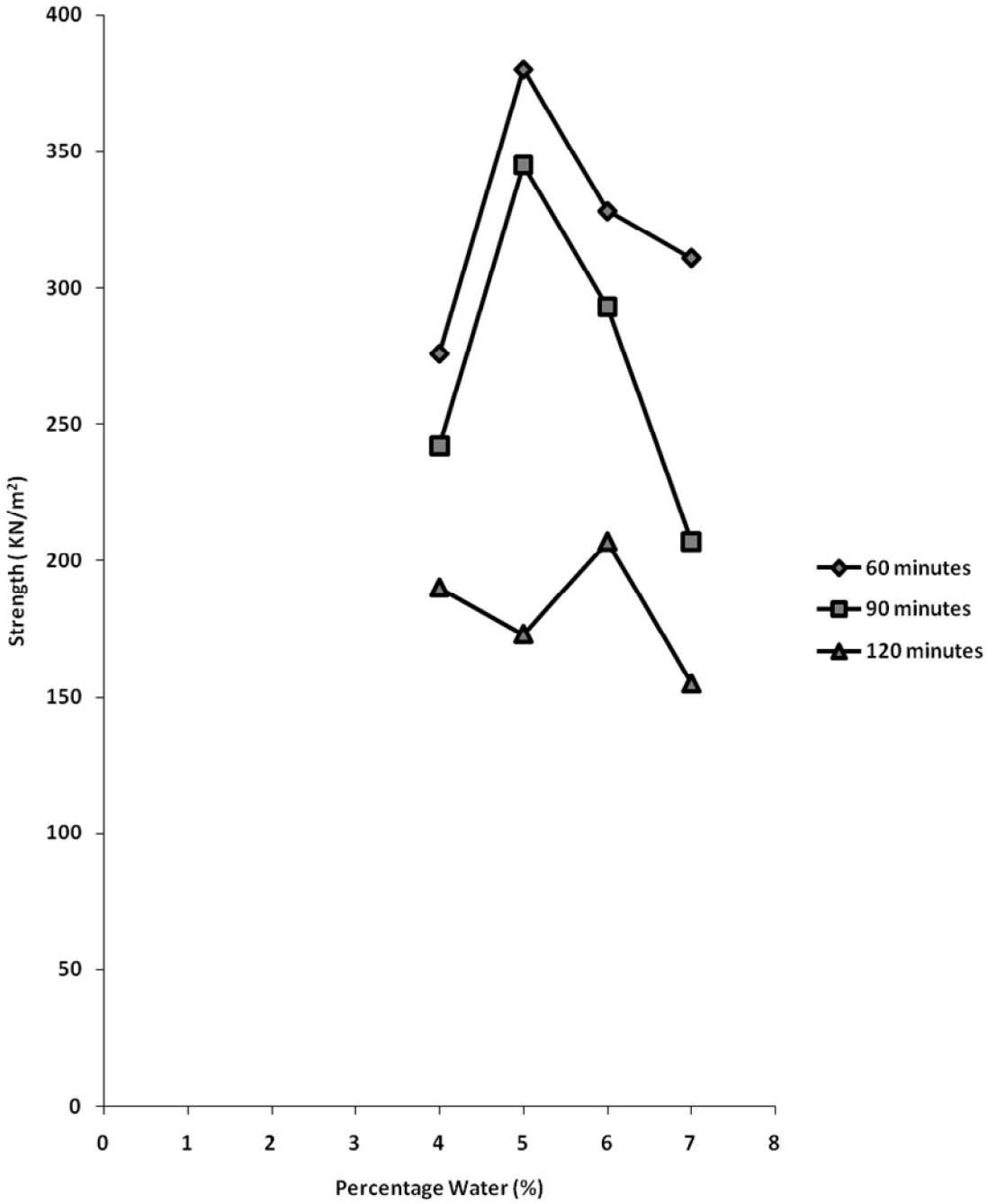


Figure 4.21: Effect of baked strength property of 4% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 7% water content.

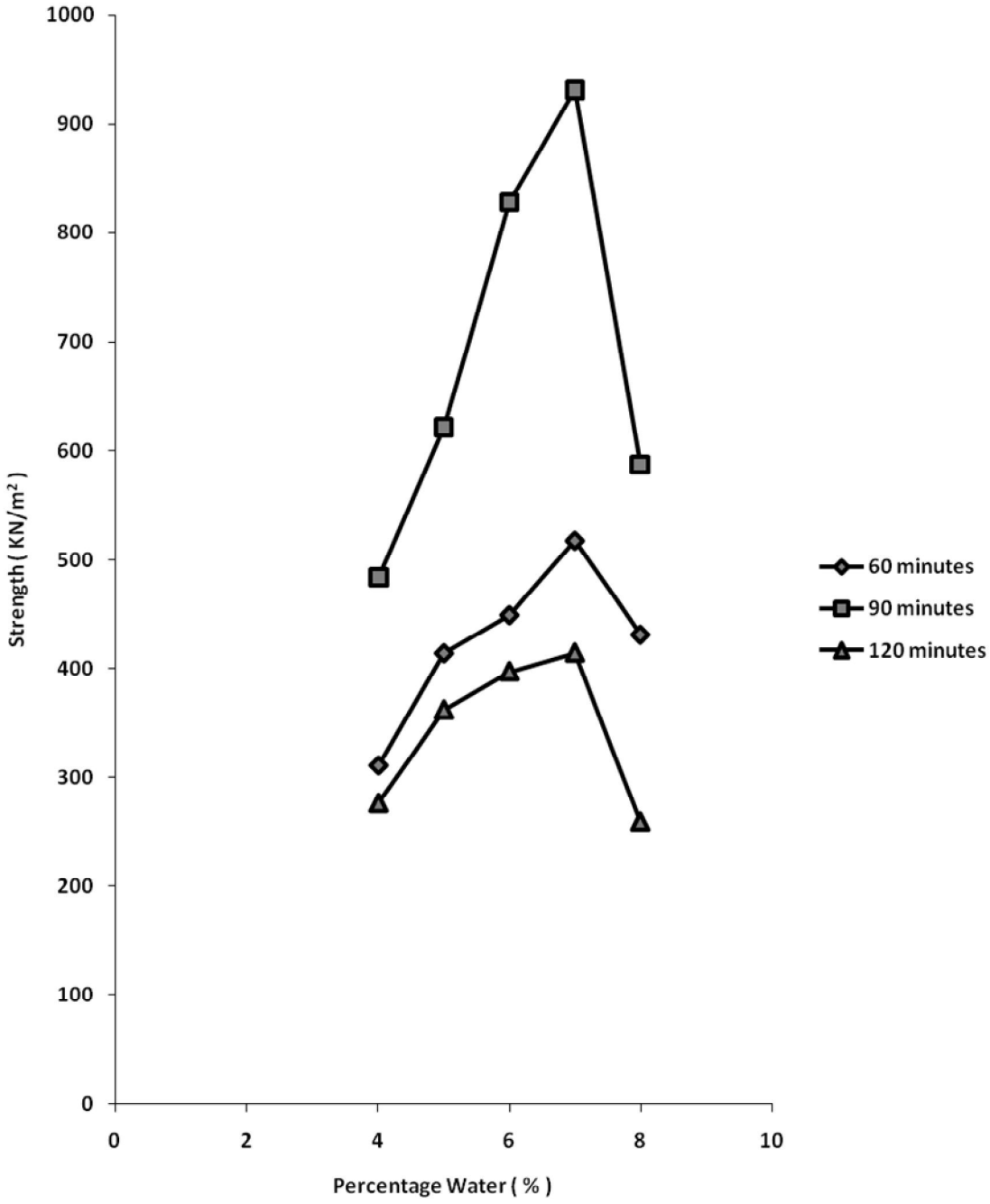


Figure 4.22: Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

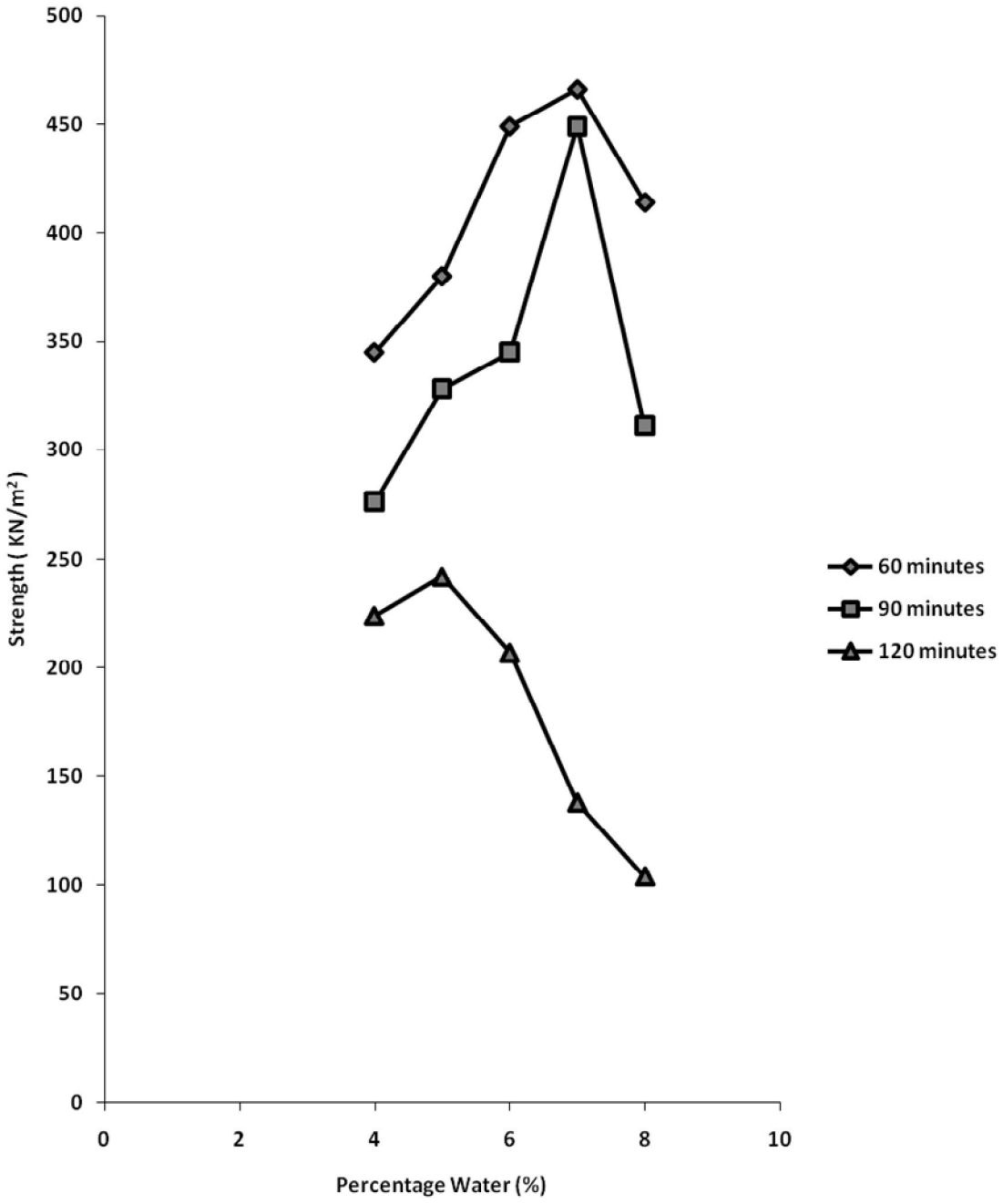


Figure 4.23: Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

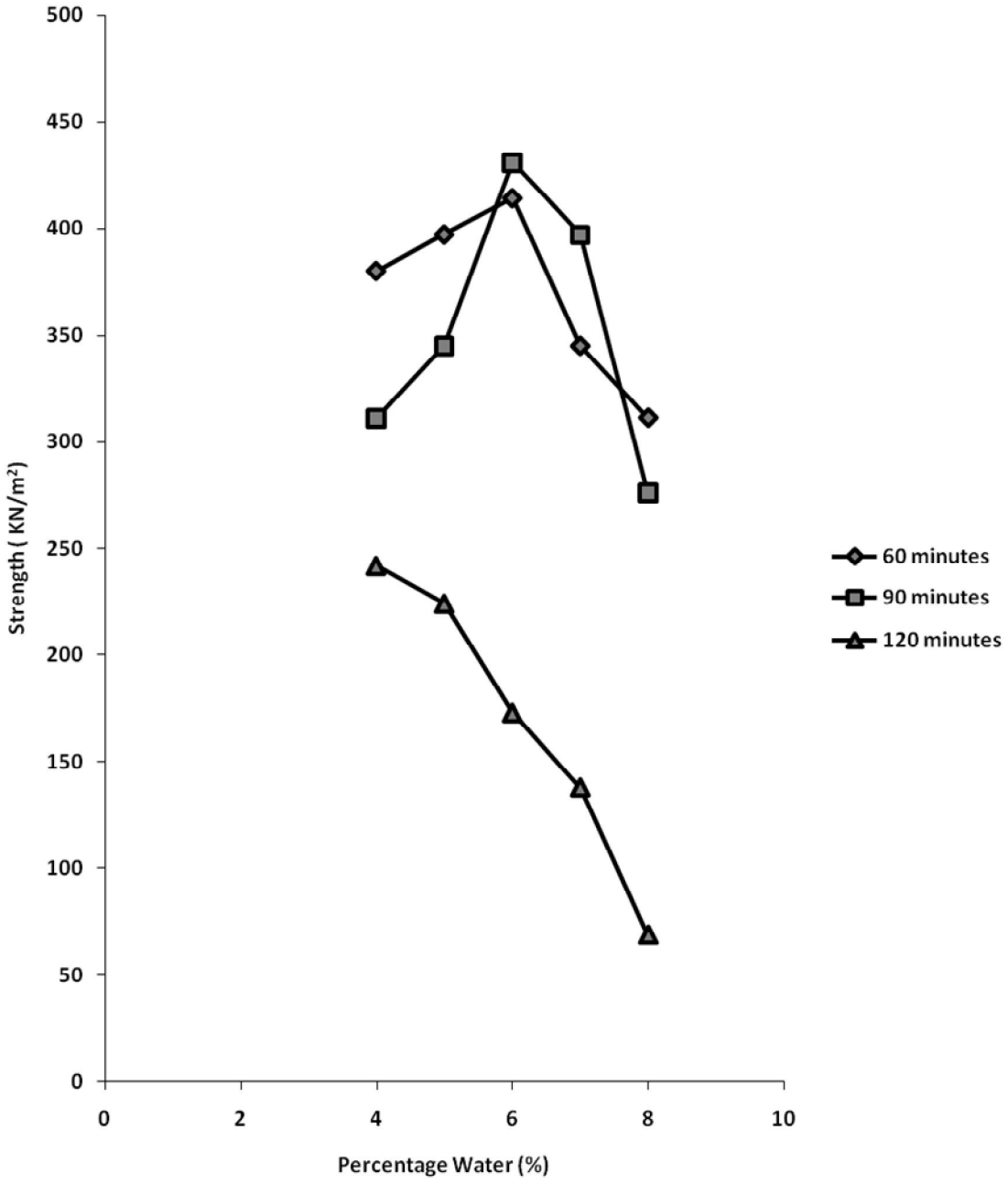


Figure 4.24: Effect of baked strength property of 5% *cissus populnea* and 0.5% Cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

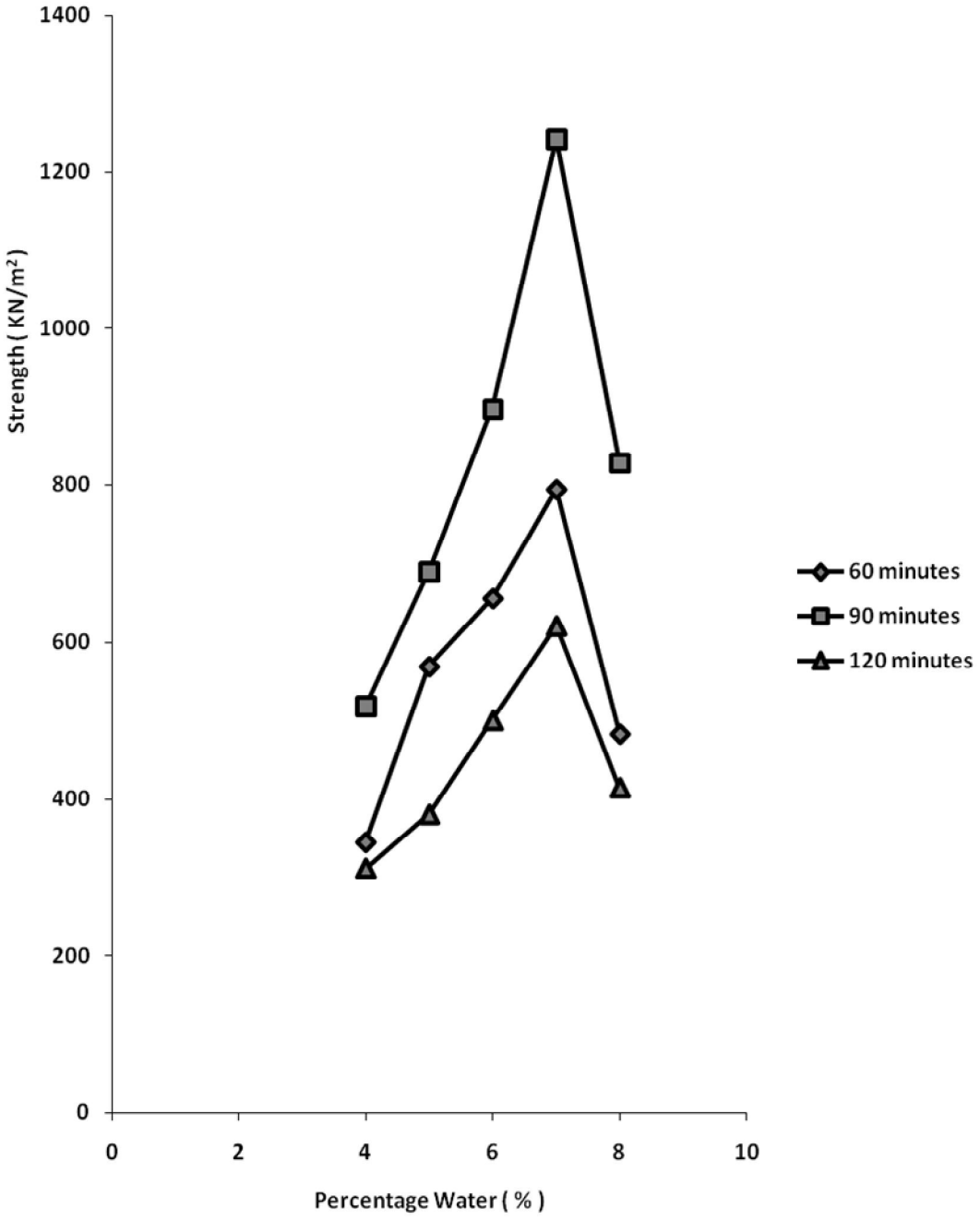


Figure 4.25: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

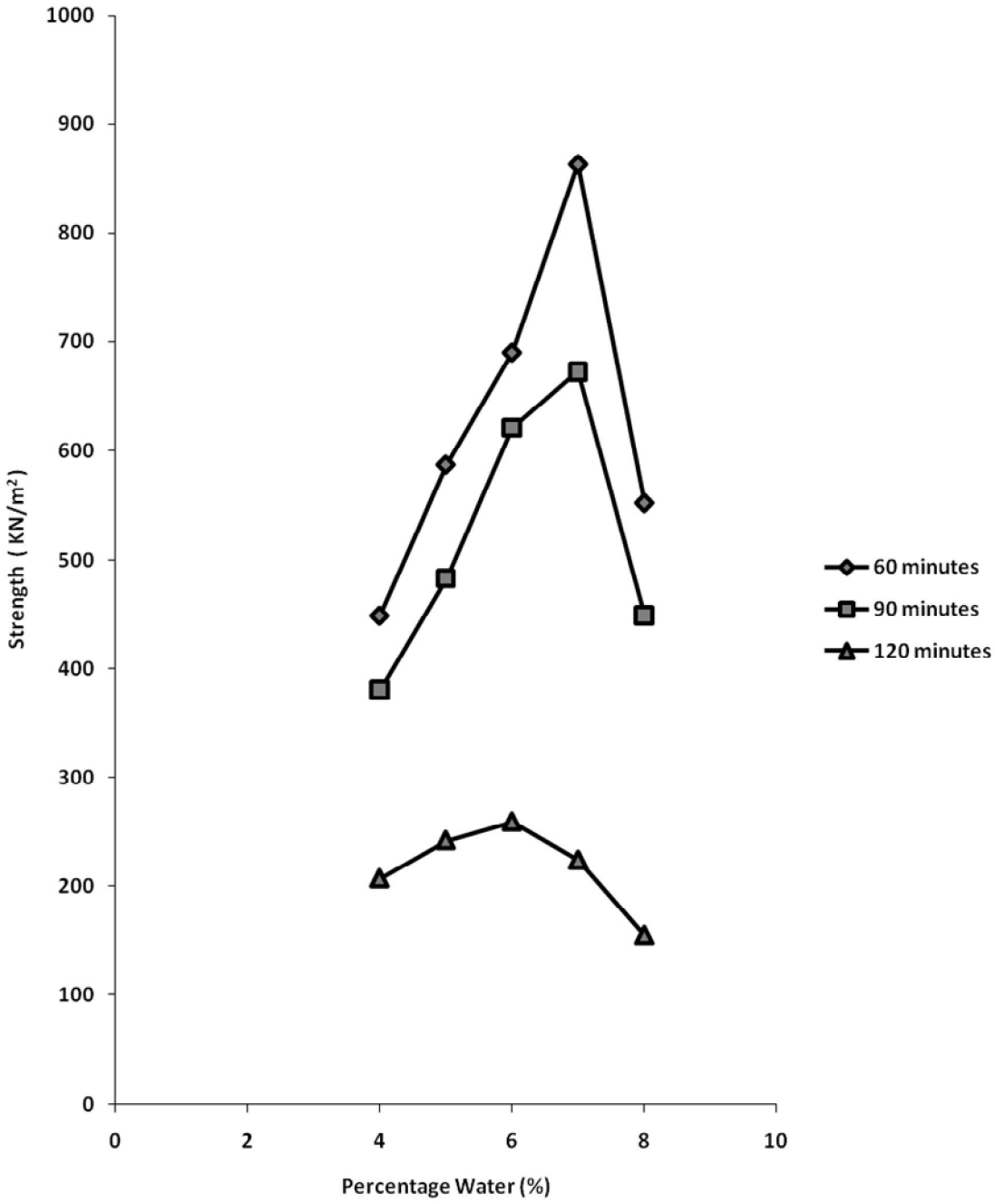


Figure 4.26: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

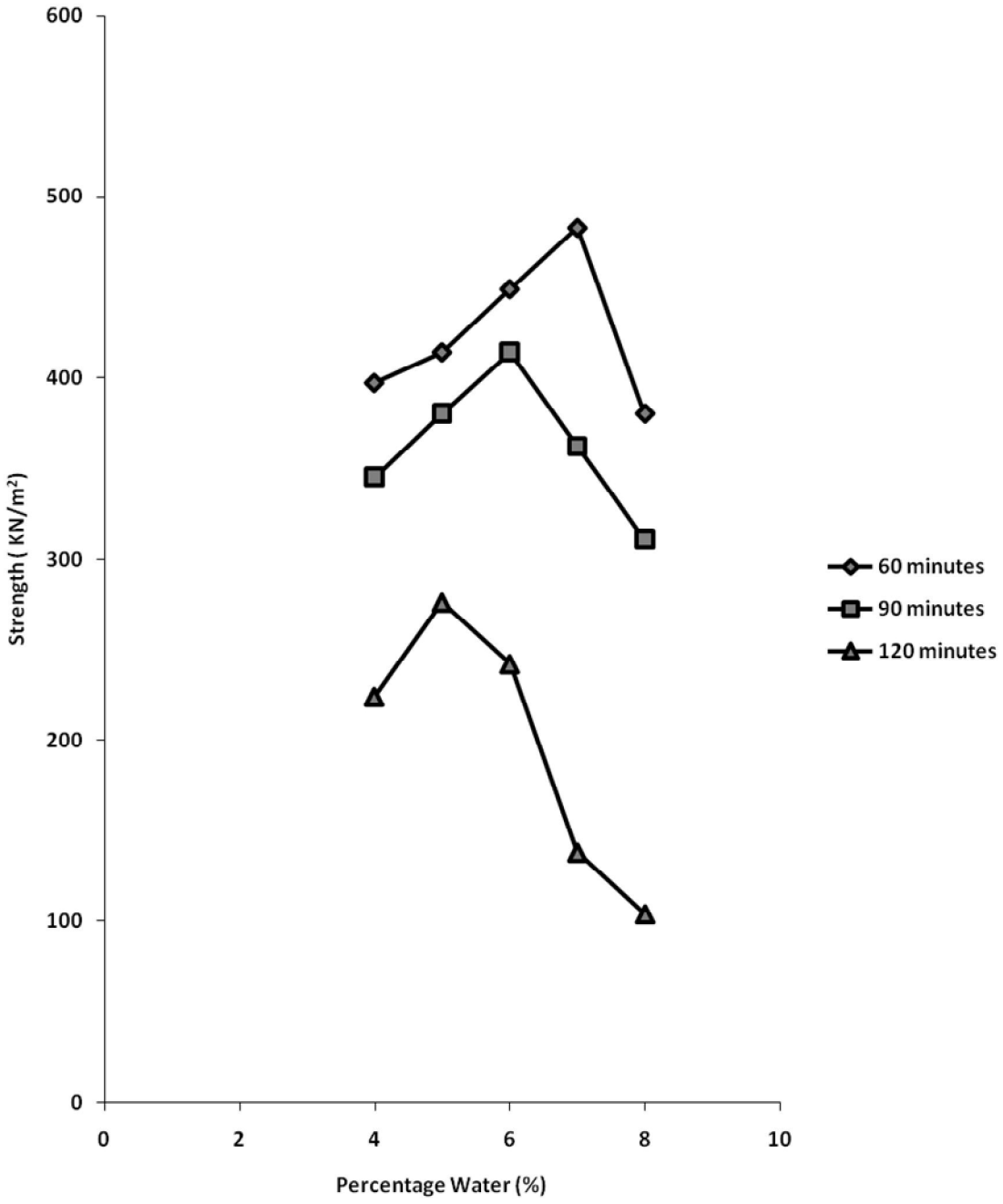


Figure 4.27: Effect of baked strength property of 6% *cissus populnea* and 0.5% cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

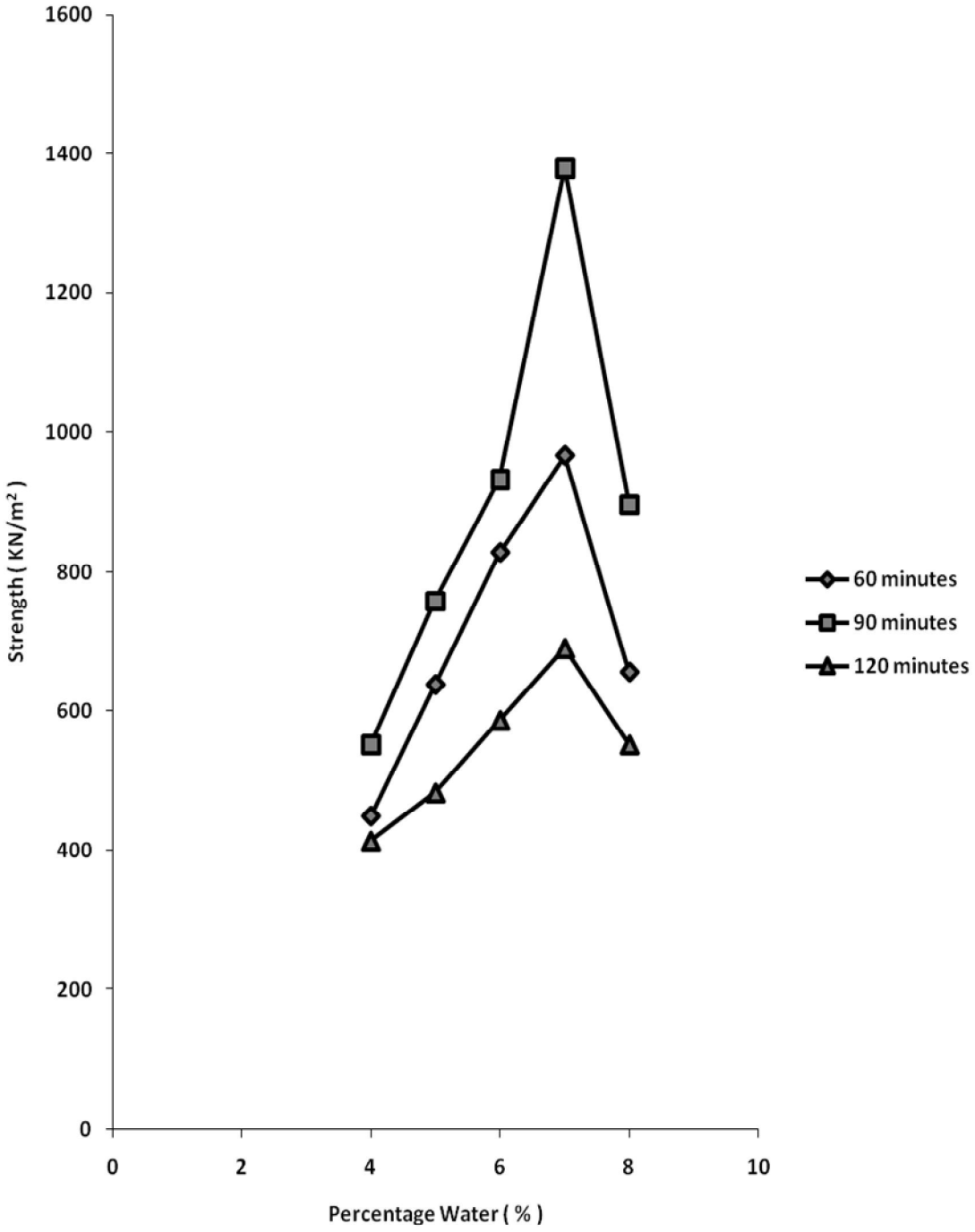


Figure 4.28: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch at baked temperature of 160^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

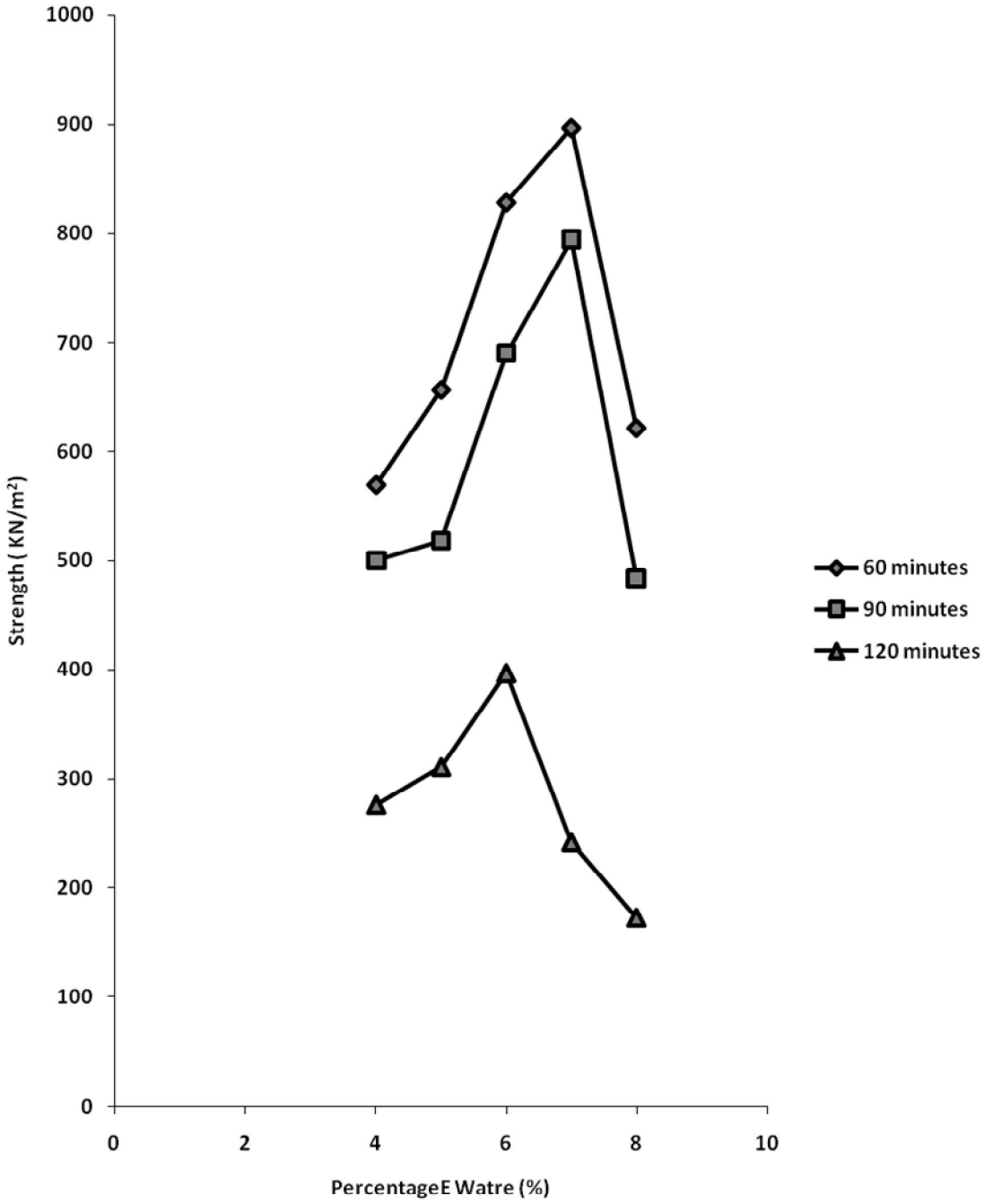


Figure 4.29: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch at baked temperature of 180^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

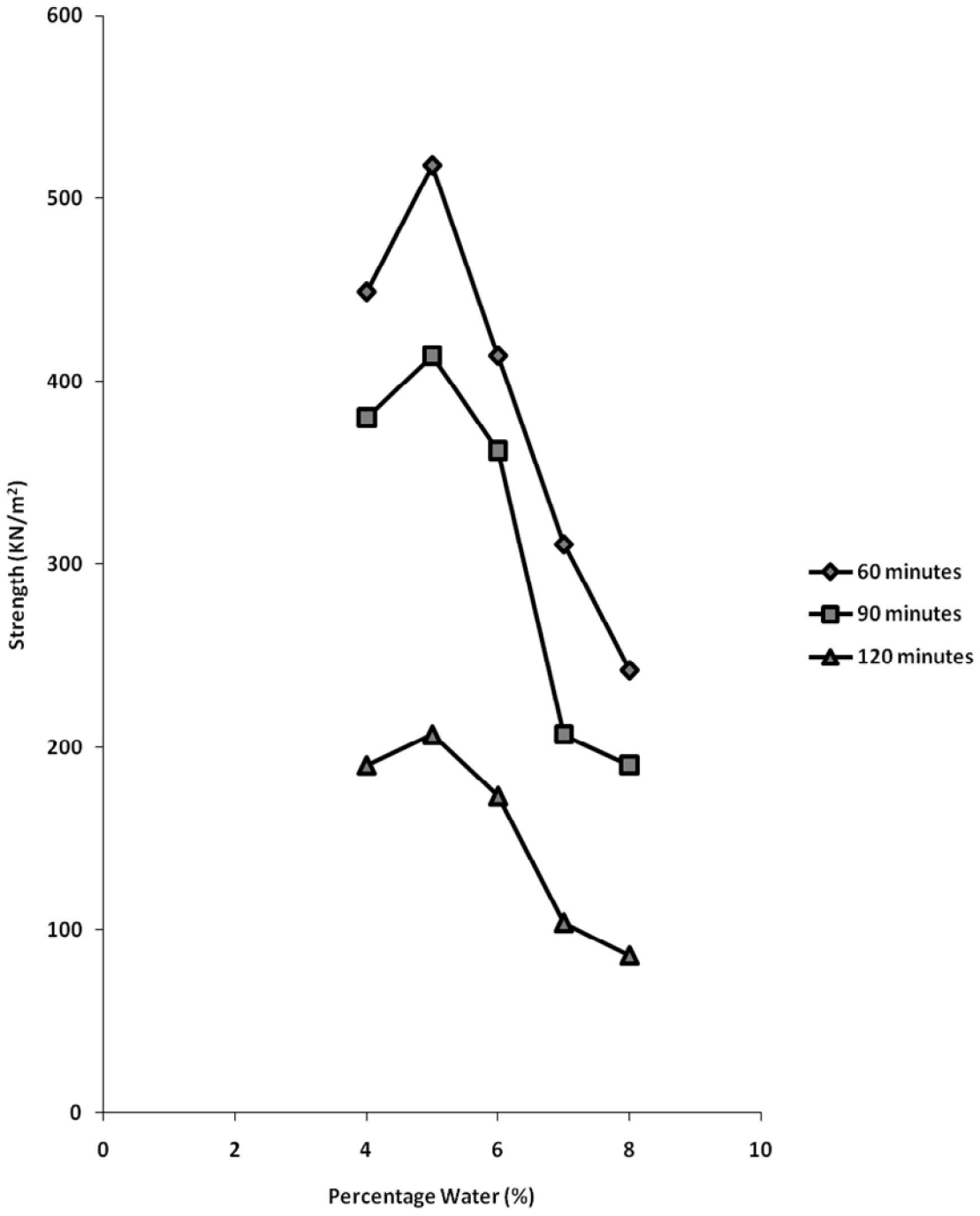


Figure 4.30: Effect of baked strength property of 7% *cissus populnea* and 0.5% cassava starch at baked temperature of 200^0C, baking time of 1, 1.5 and 2 hours at 4 – 8% water content.

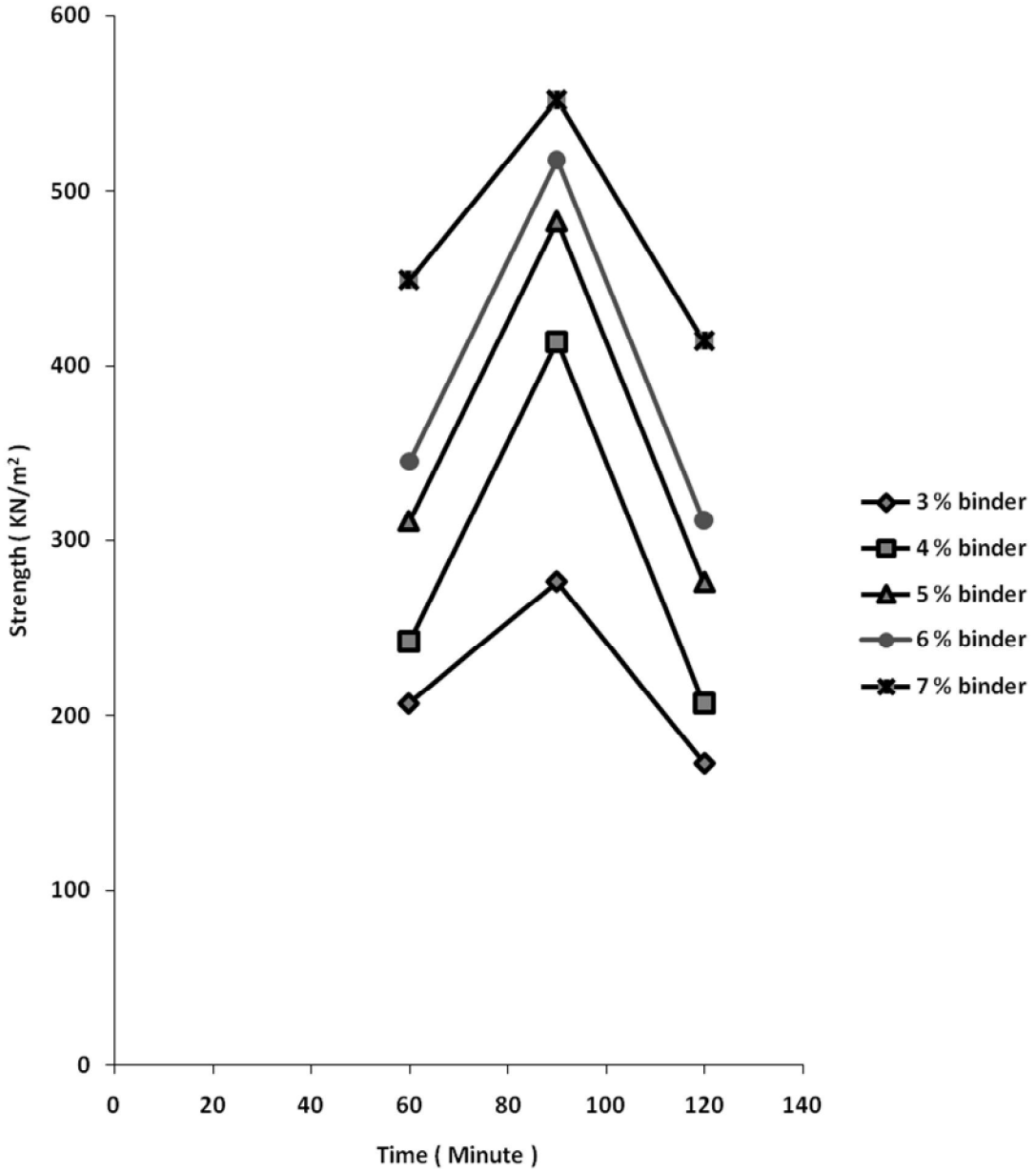


Figure 4.31: Effect of baked strength property of 3 - 7% *cissus populnea,* 0.5% cassava starch, 4% water baked at a temperature of 160^0C, and baking time of 1 - 2 hours.

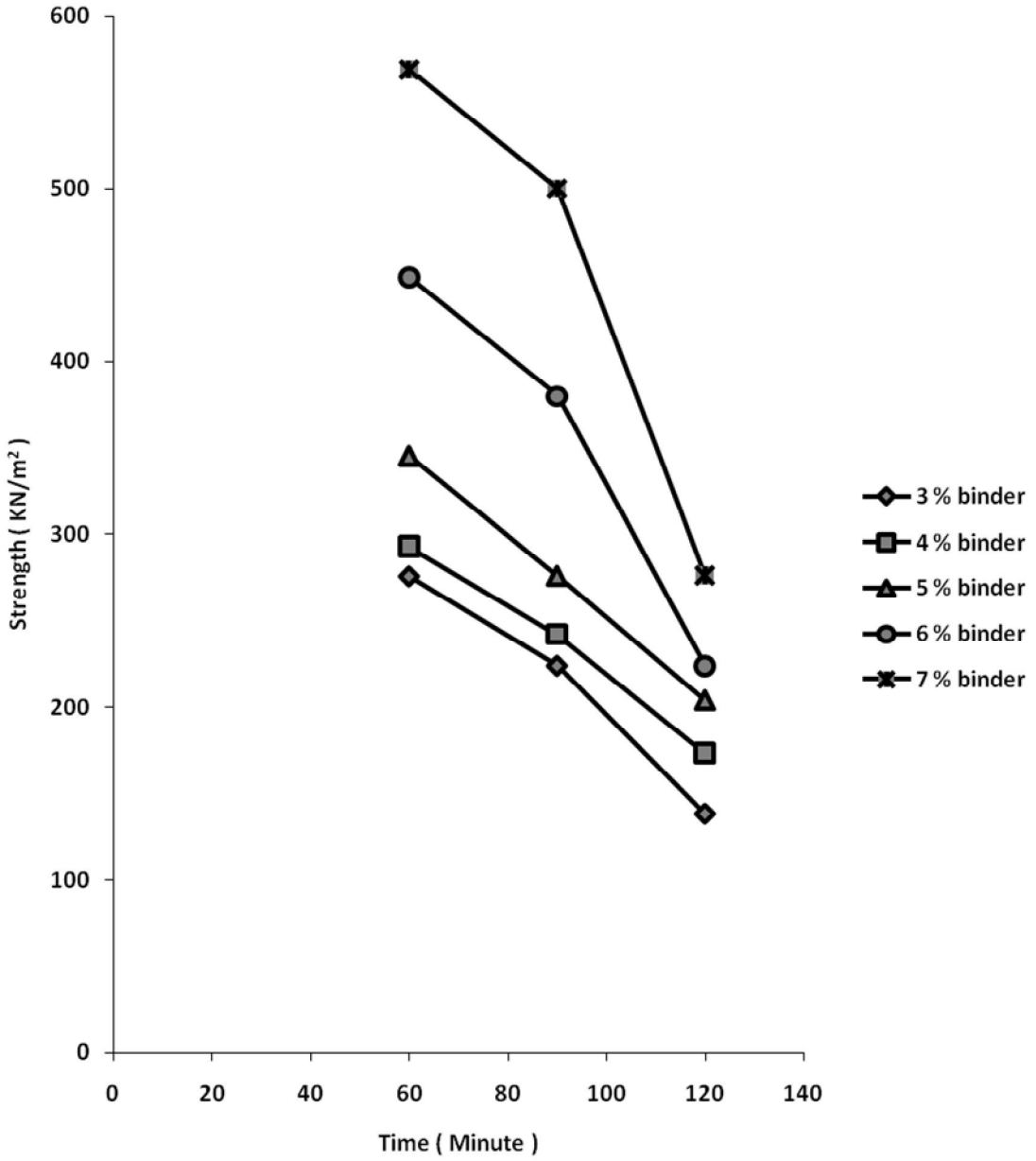


Figure 4.32: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 4% water baked at a temperature of 180^0C, and baking time of 1 - 2 hours.

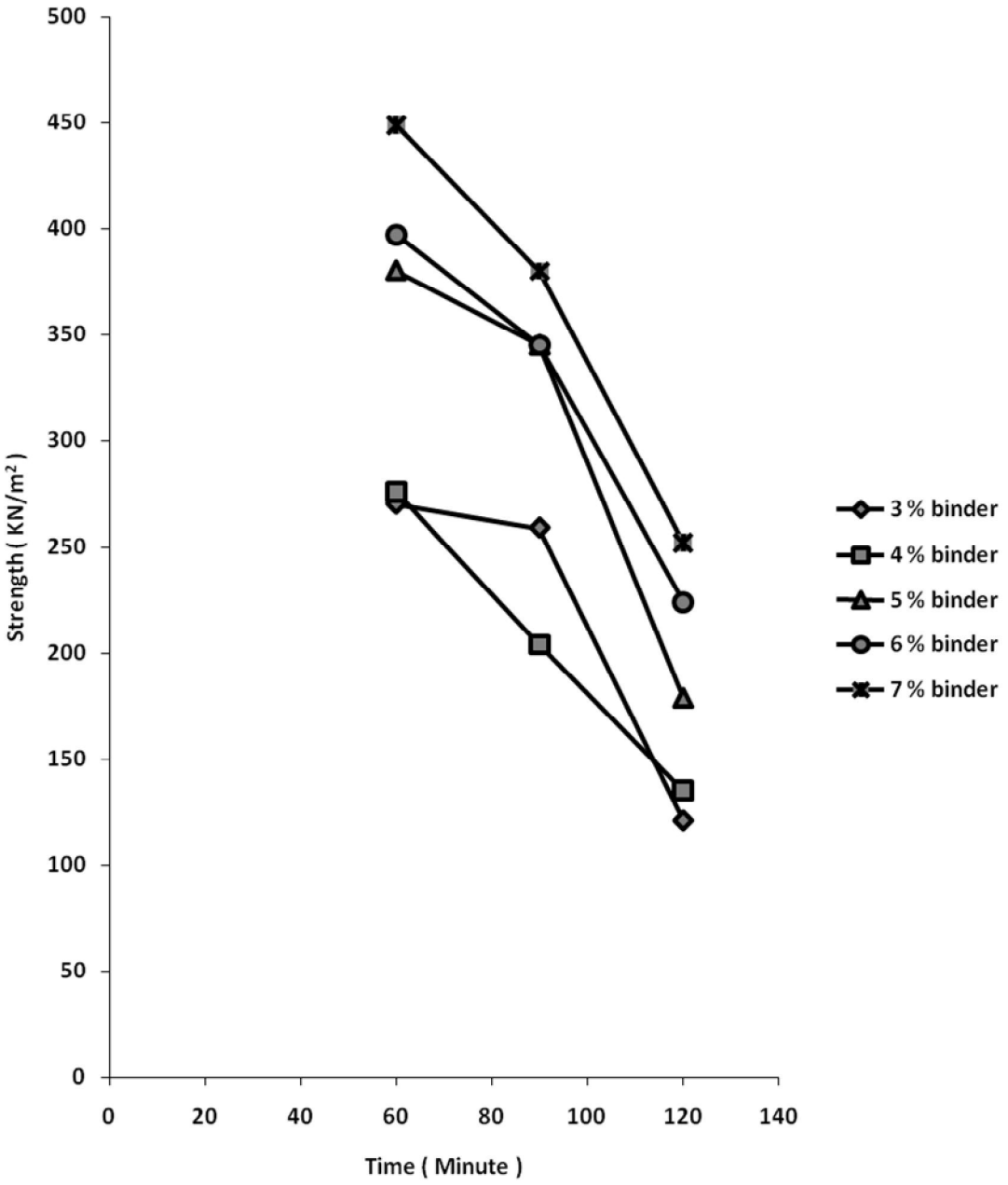


Figure 4.33: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 4% water baked at a temperature of 200^0C, and baking time of 1 - 2 hours.

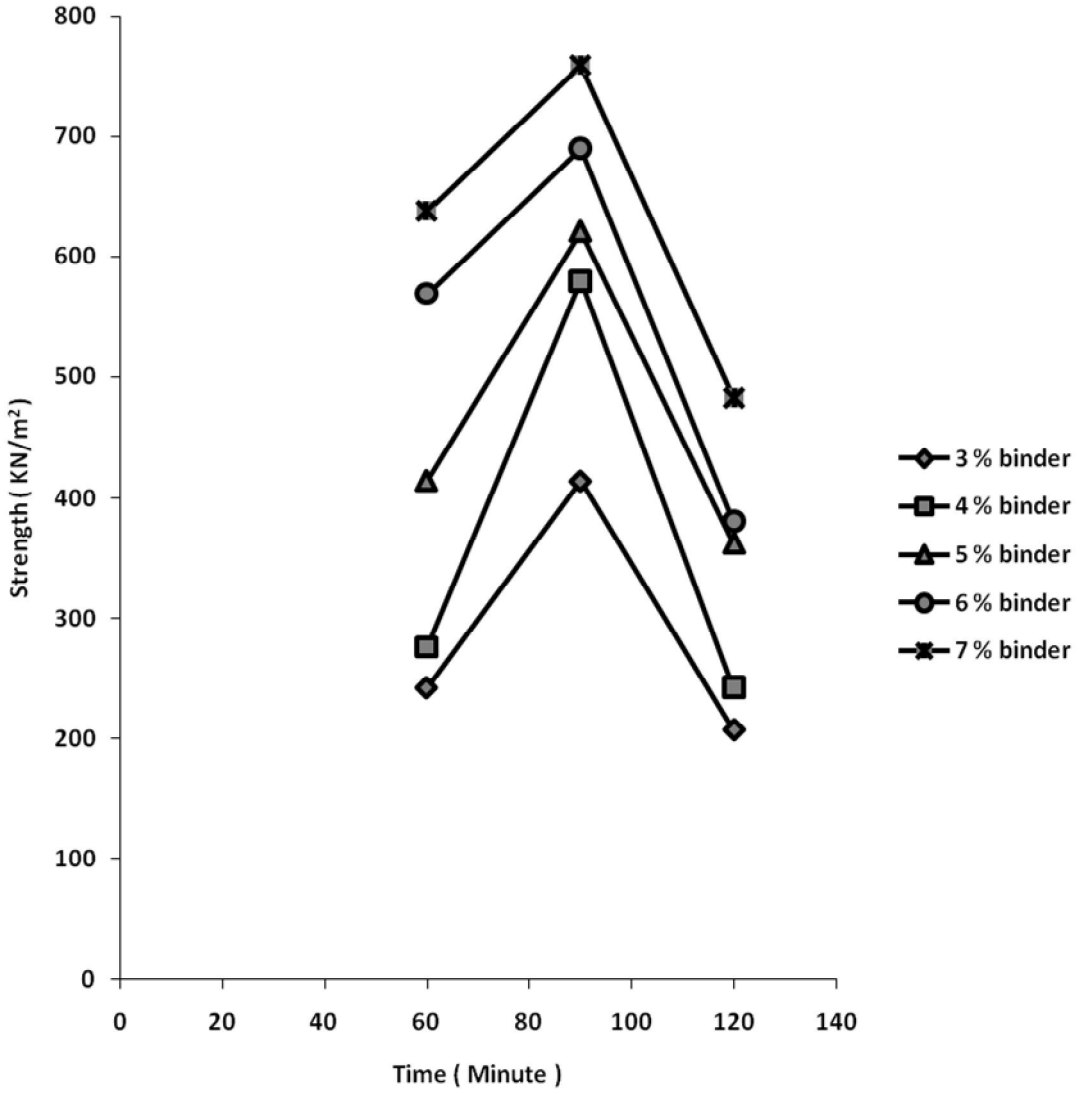


Figure 4.34: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 160^0C, baking time of 1 - 2 hours.

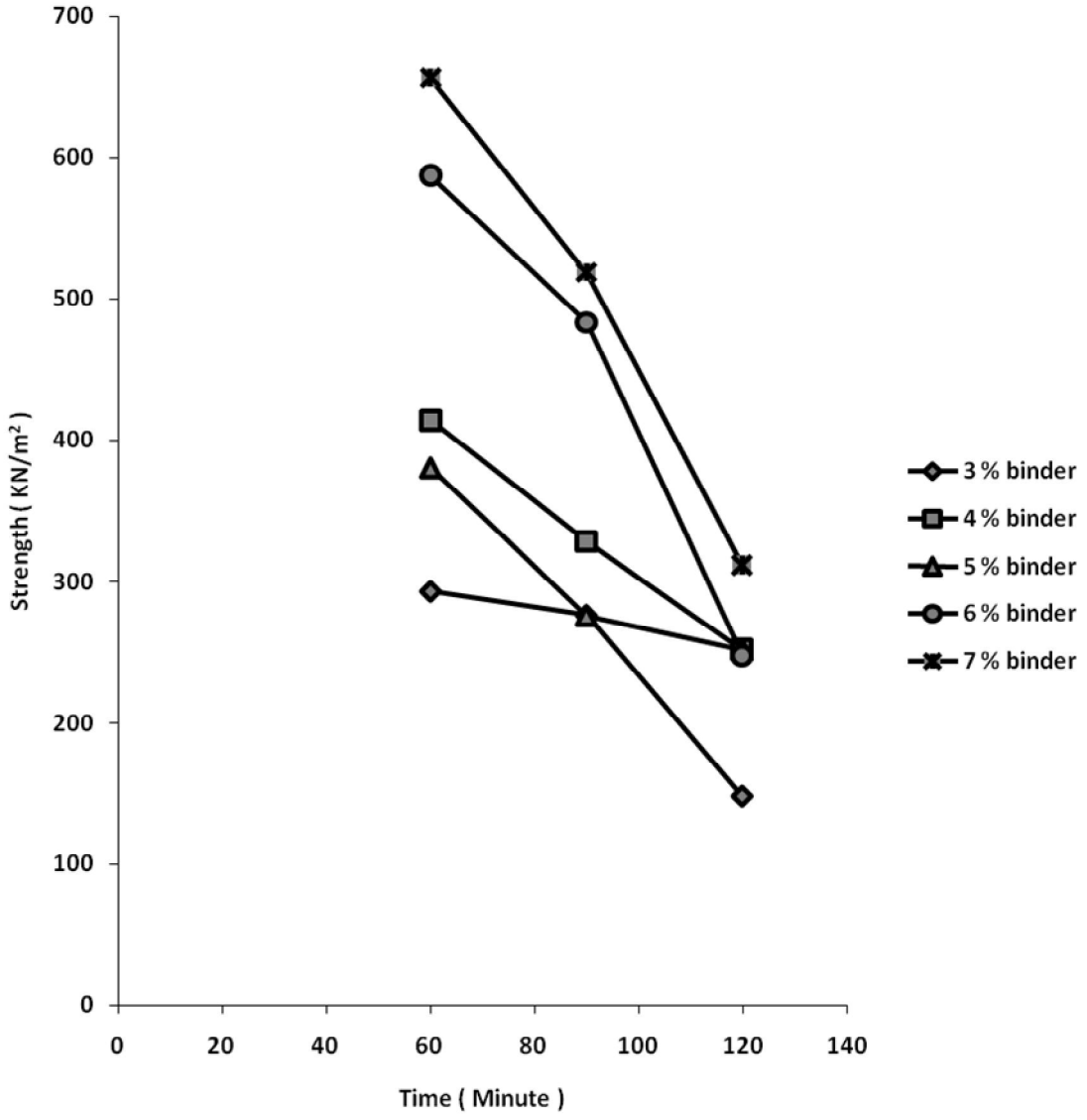


Figure 4.35: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 180^0C, baking time of 1 - 2 hours.

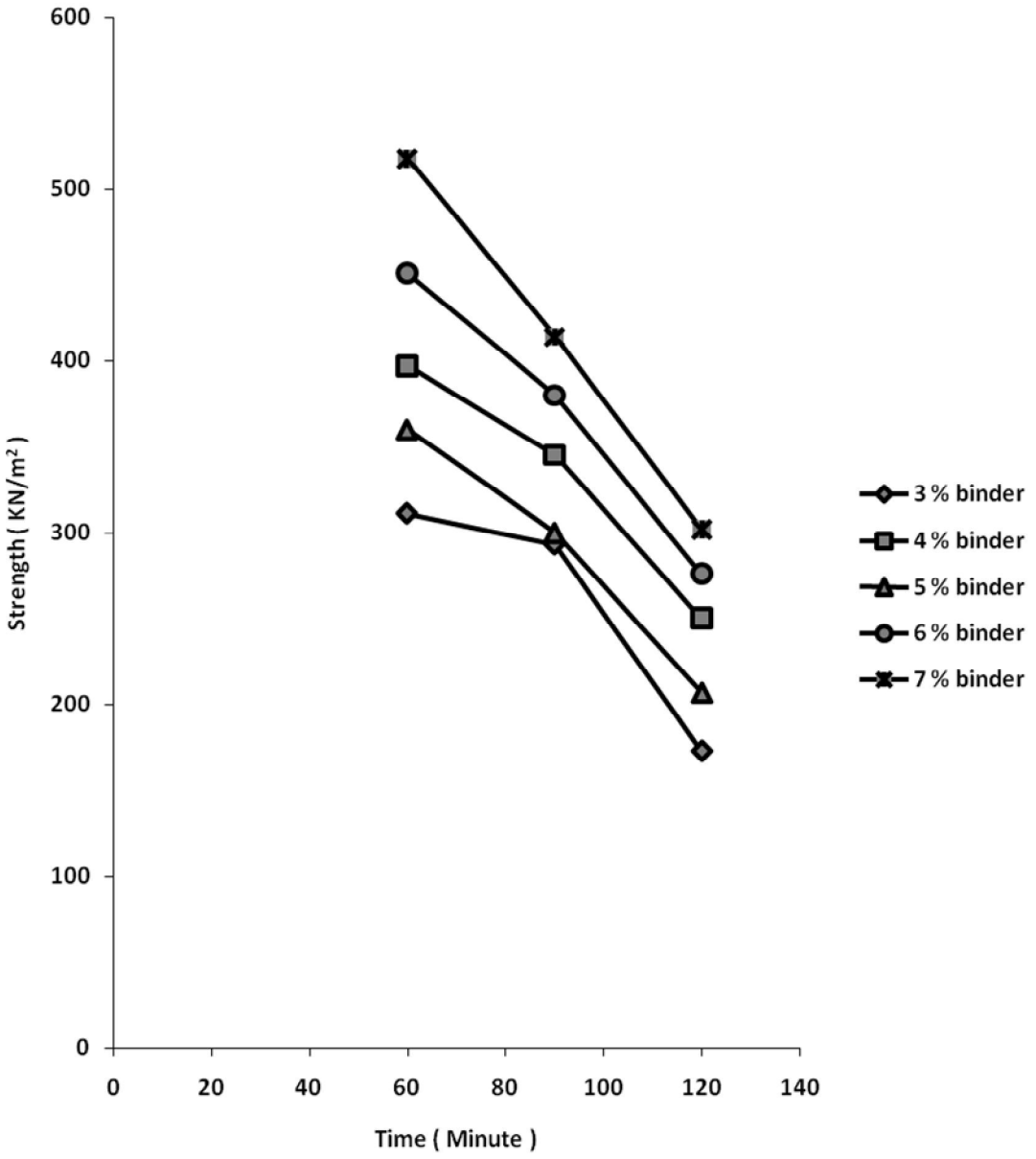


Figure 4.36: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 5% water baked at a temperature of 200^0C, baking time of 1 - 2 hours.

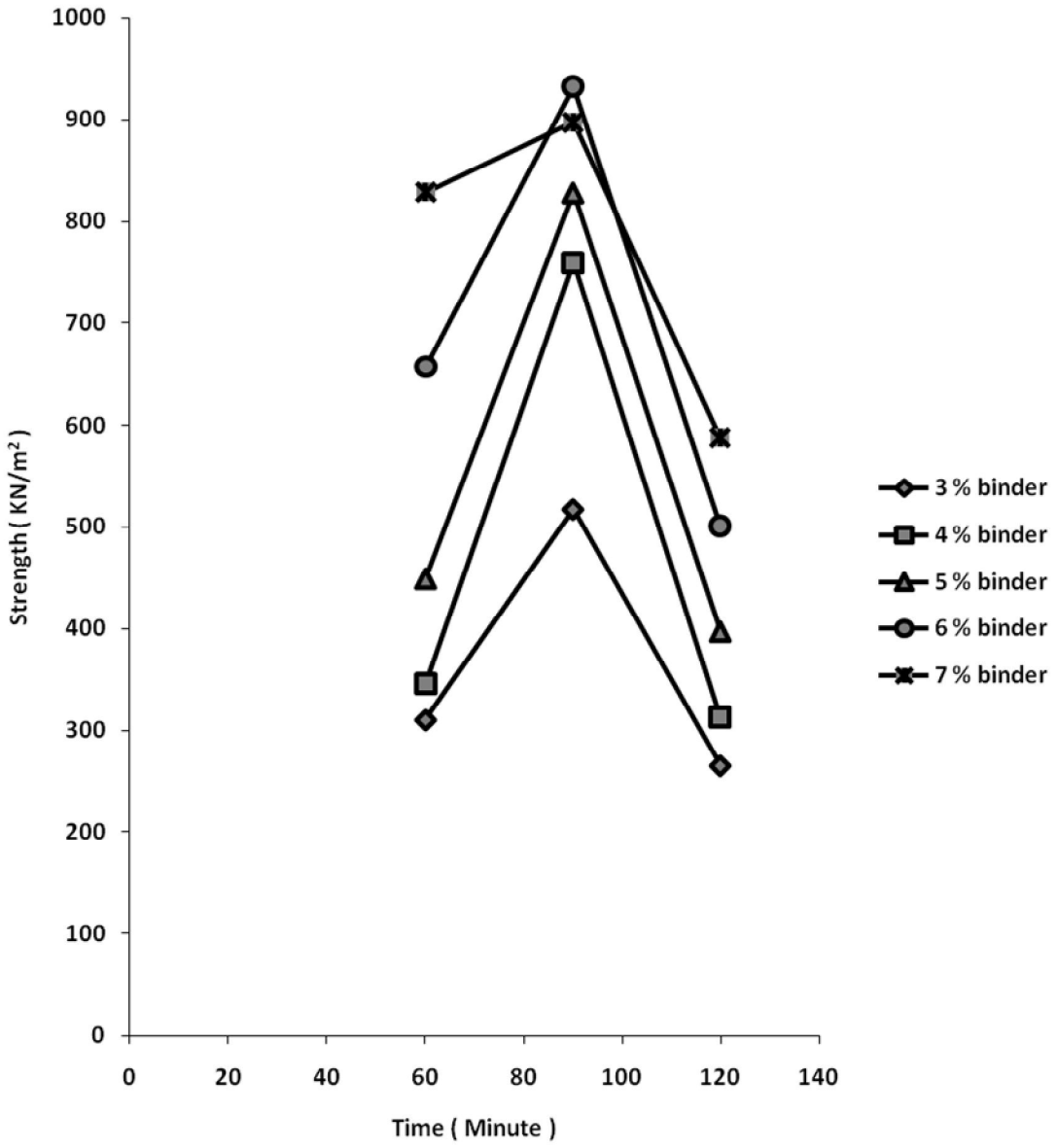


Figure 4.37: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 160^0C, baking time of 1 - 2 hours.

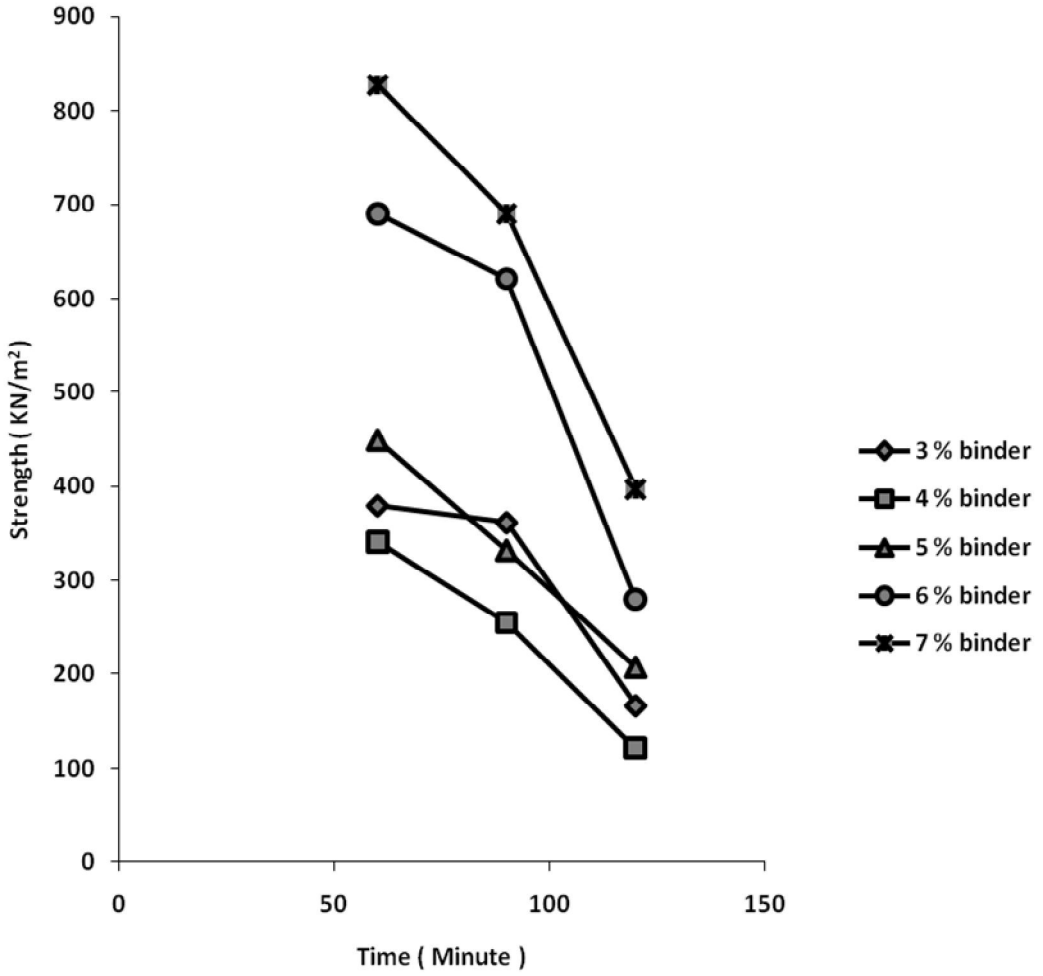


Figure 4.38: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 180^0C, baking time of 1 - 2 hours.

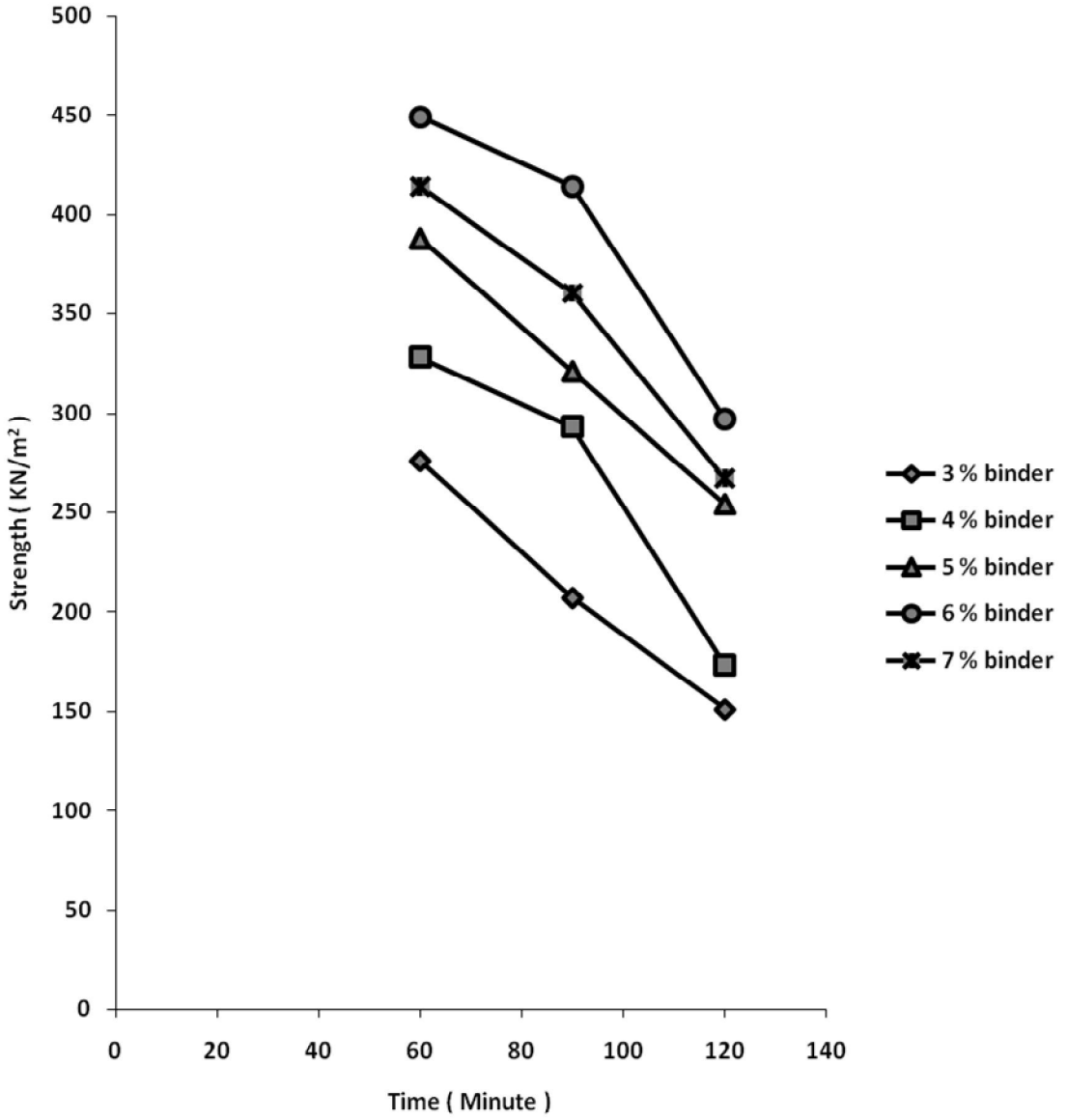


Figure 4.39: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 6% water baked at a temperature of 200^0C, baking time of 1 - 2 hours.

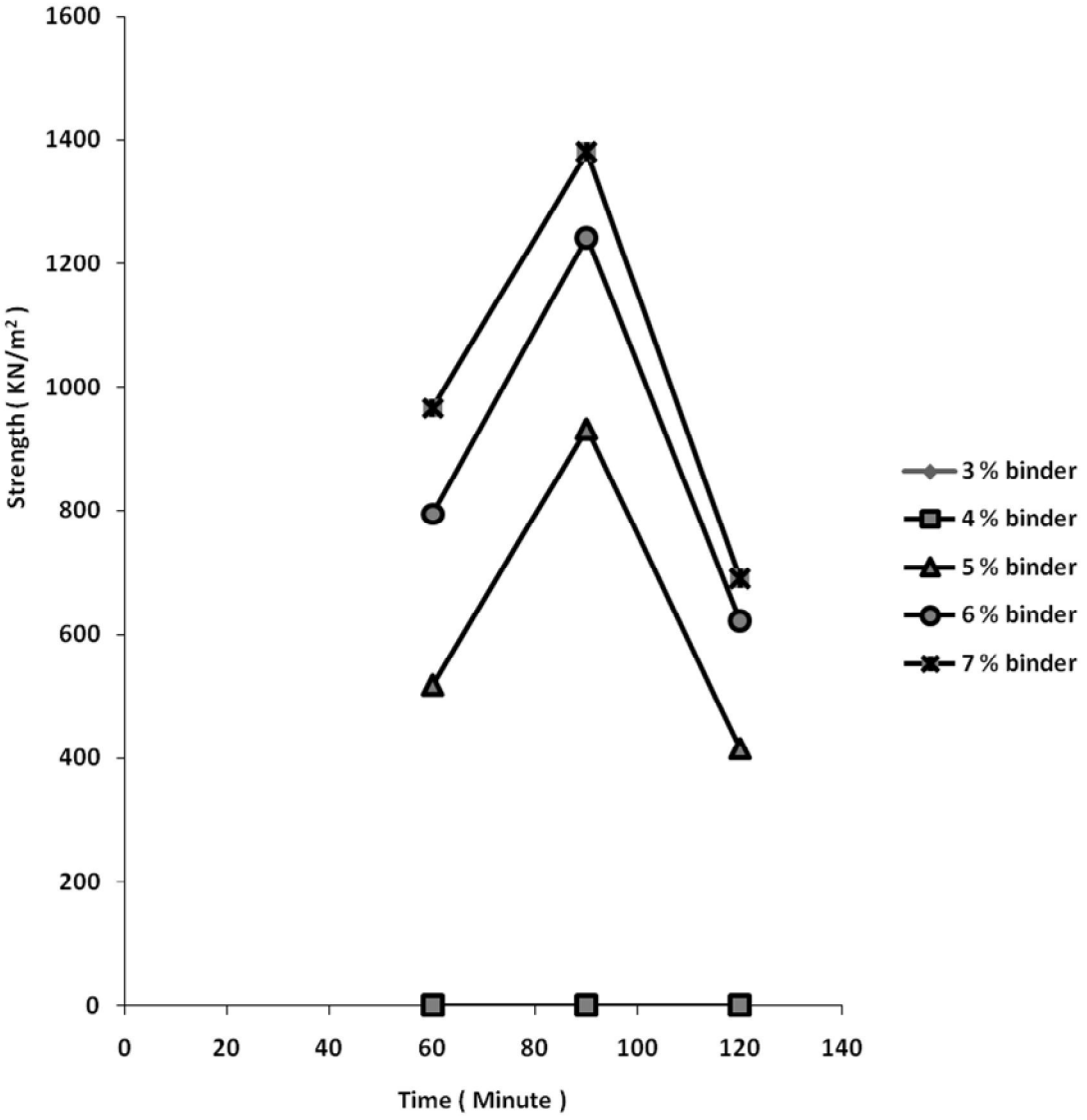


Figure 4.40: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 160^0C, baking time of 1 - 2 hours.

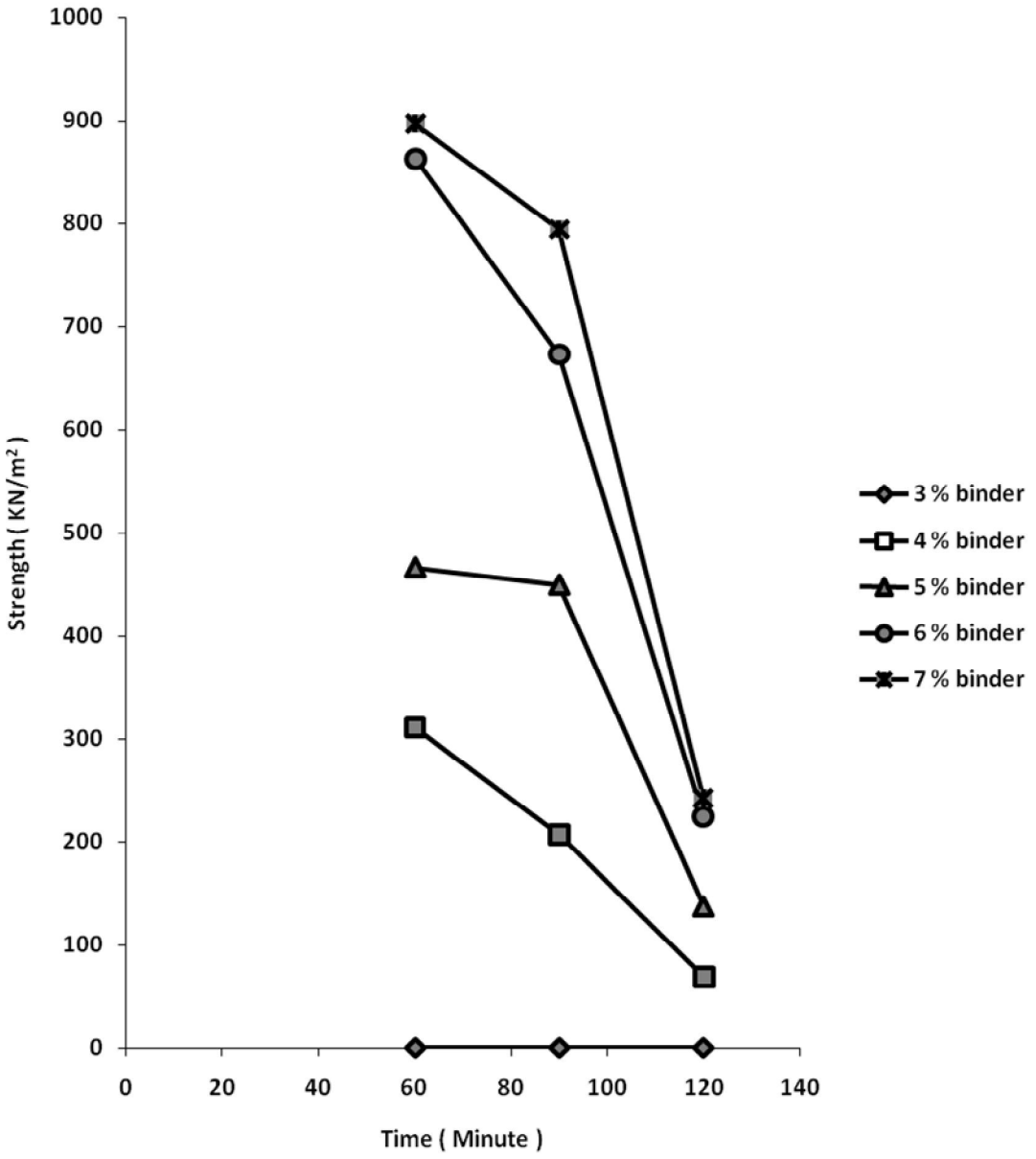


Figure 4.41: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 180^0C, baking time of 1 - 2 hours.

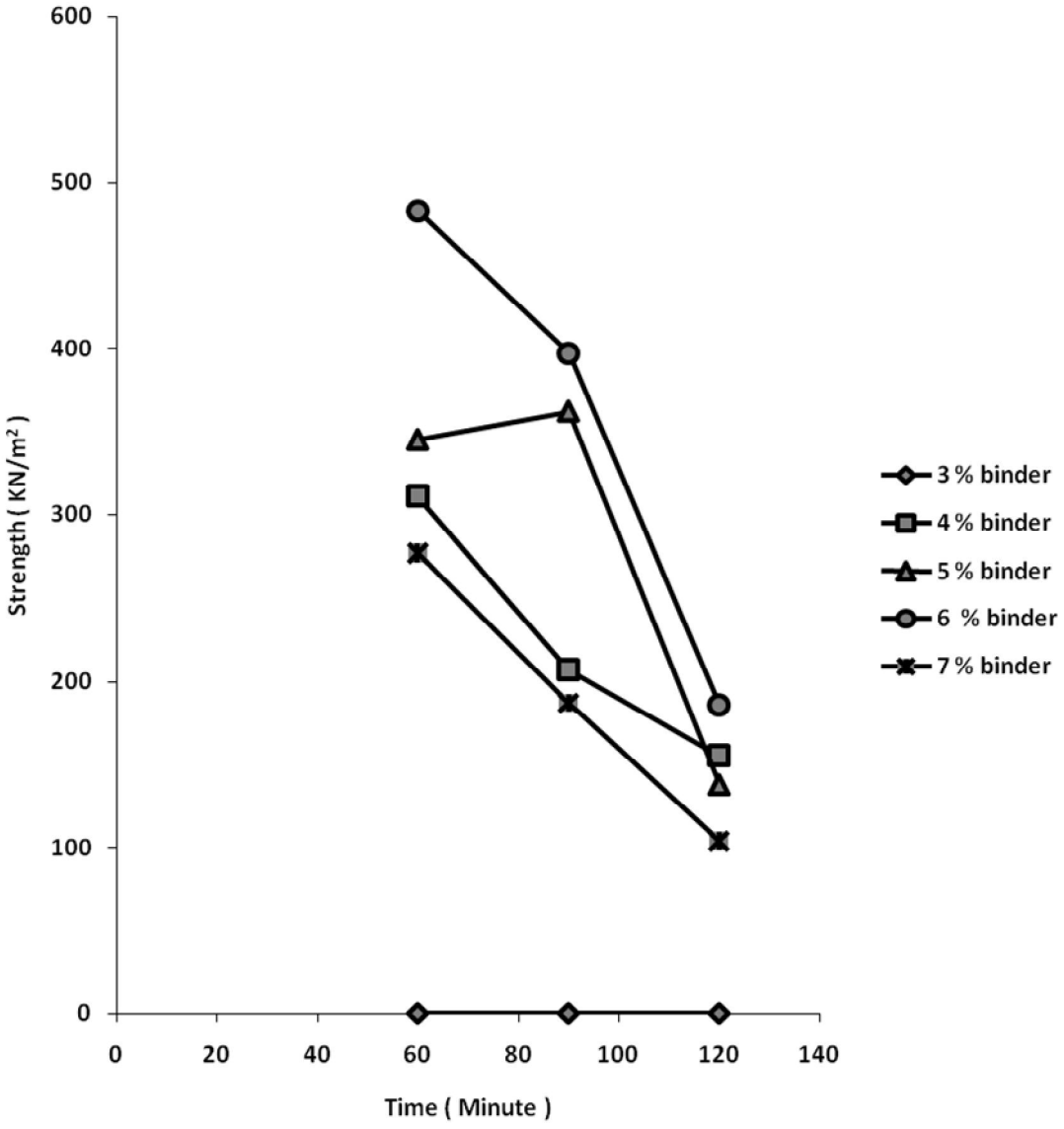


Figure 4.42: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 7% water baked at a temperature of 200^0C, baking time of 1 - 2 hour.

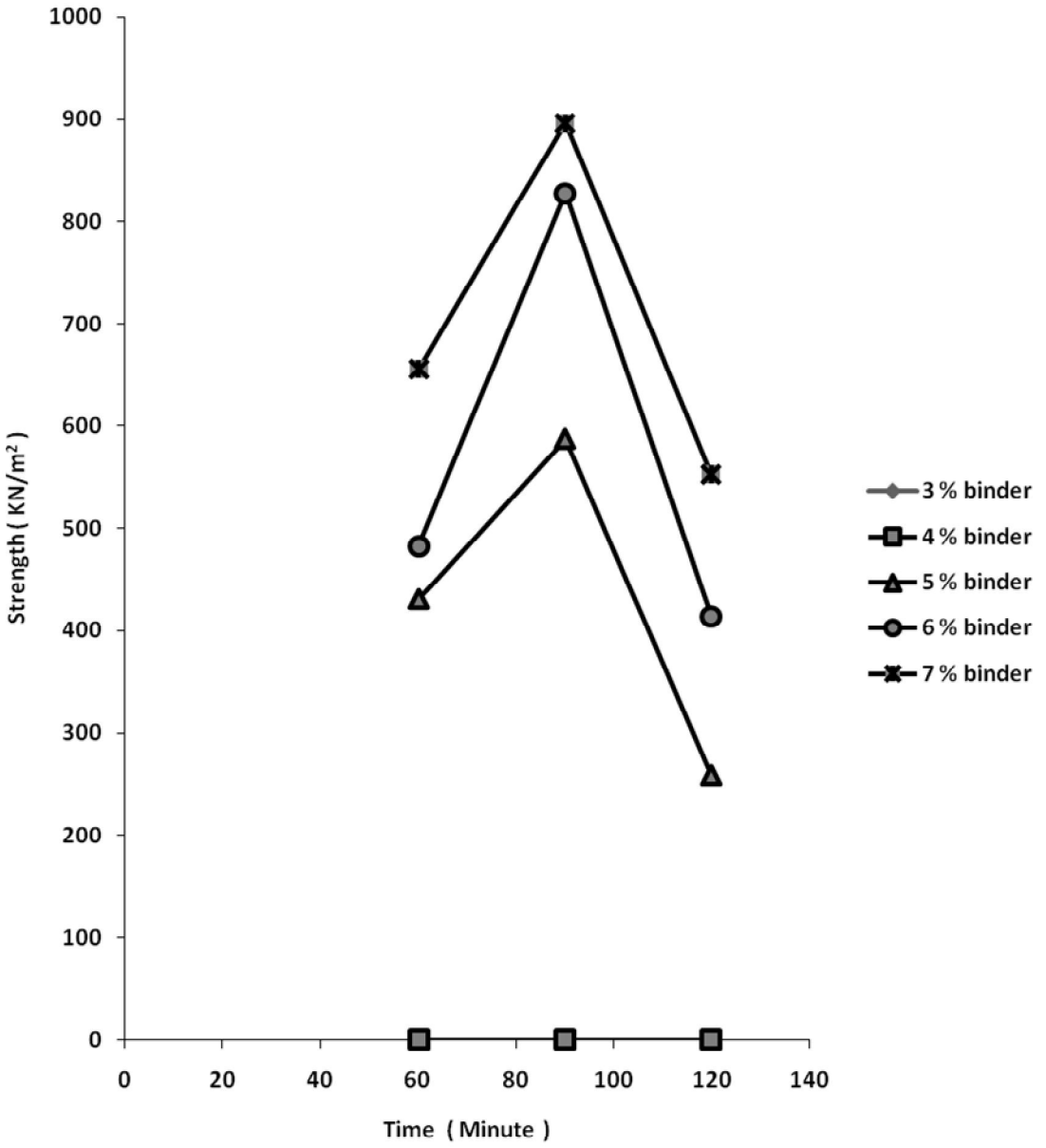


Figure 4.43: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 8% water baked at a temperature of 160^0C,baking time of 1 - 2 hours.

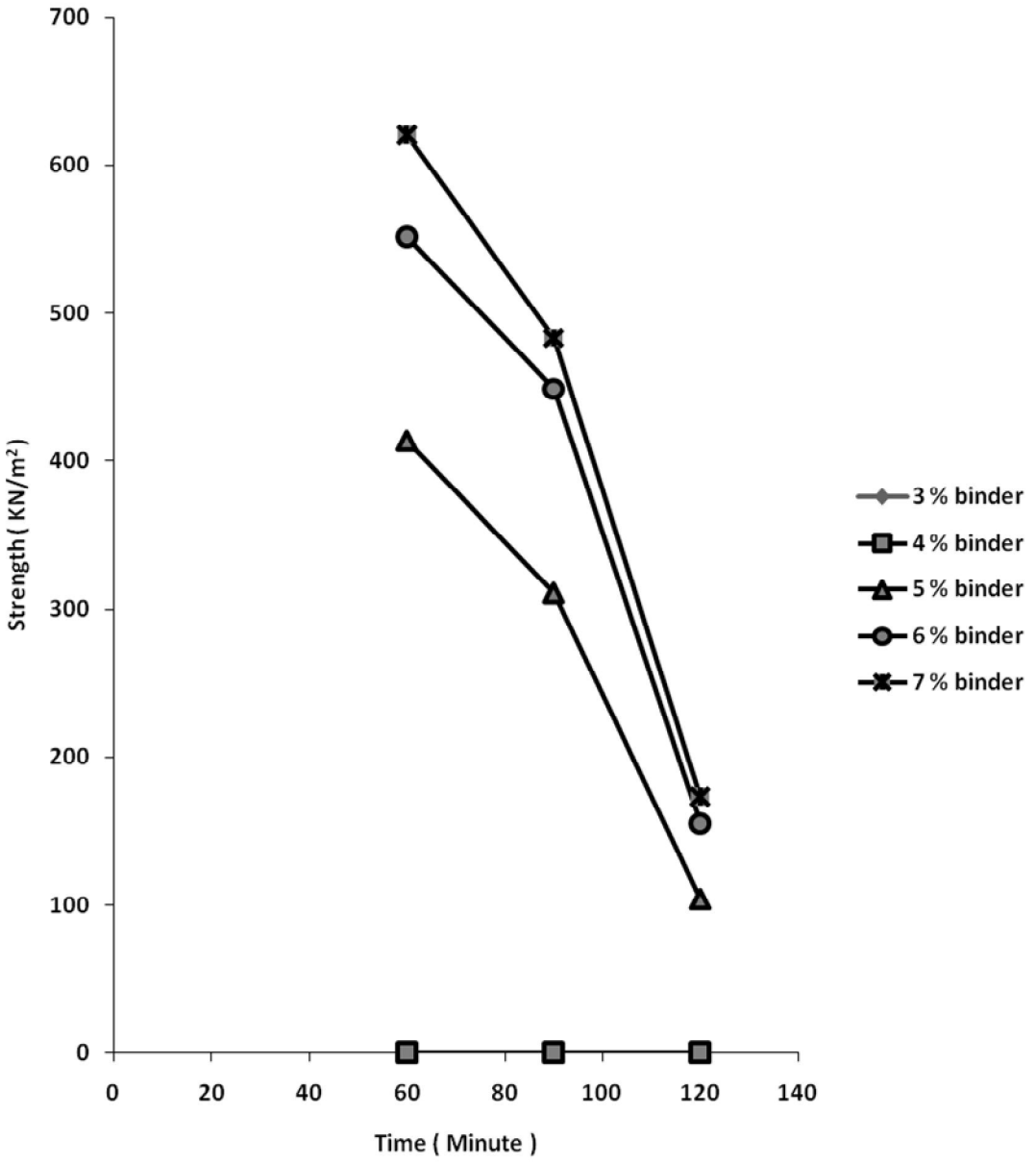


Figure 4.44: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 8% water baked at a temperature of 180^0C, baking time of 1 - 2 hours.

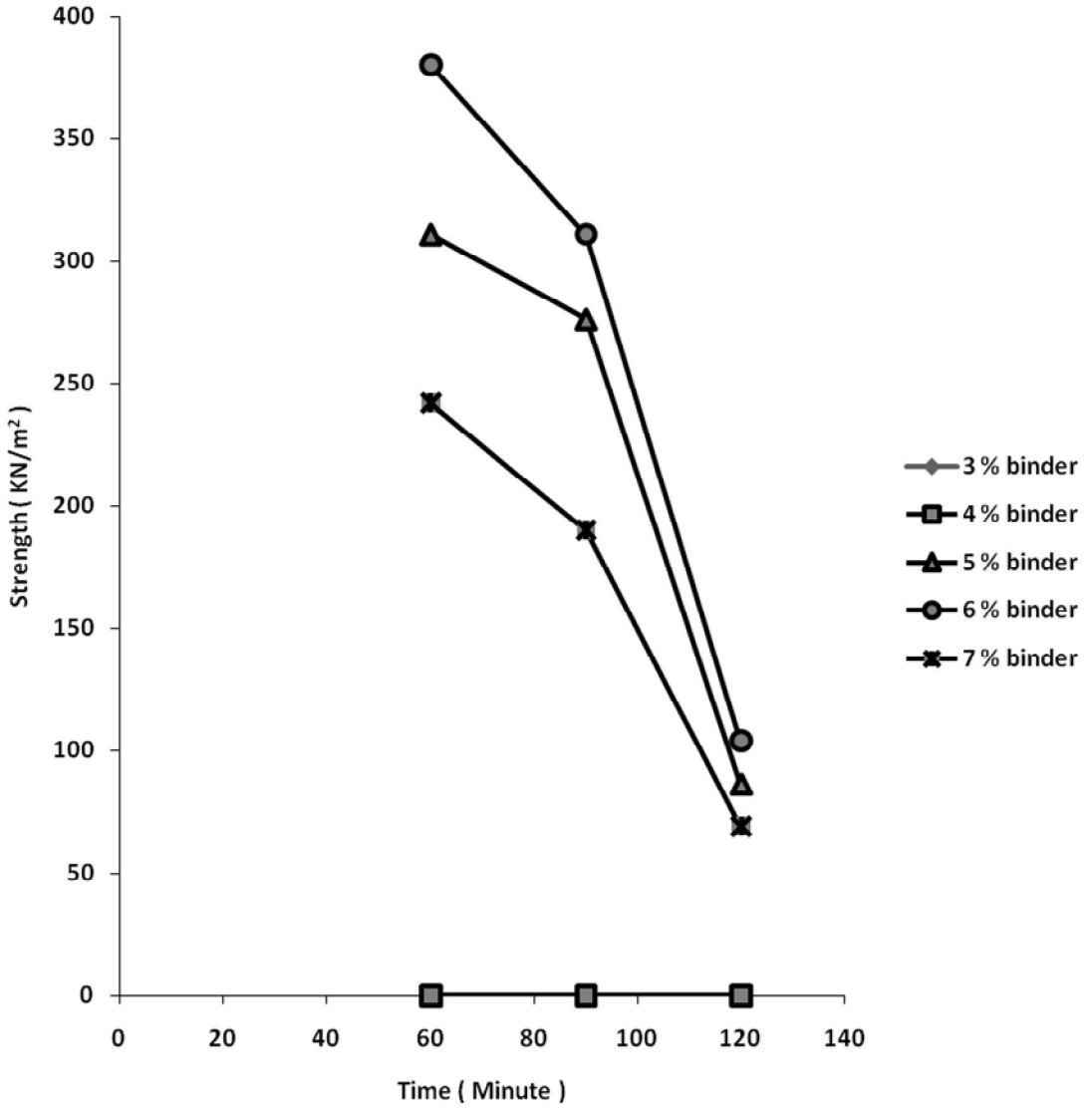


Figure 4.45: Effect of baked strength property of 3 - 7% *cissus populnea*, 0.5% cassava starch, 8% water baked at a temperature of 200^0C, baking time of 1 - 2 hours.

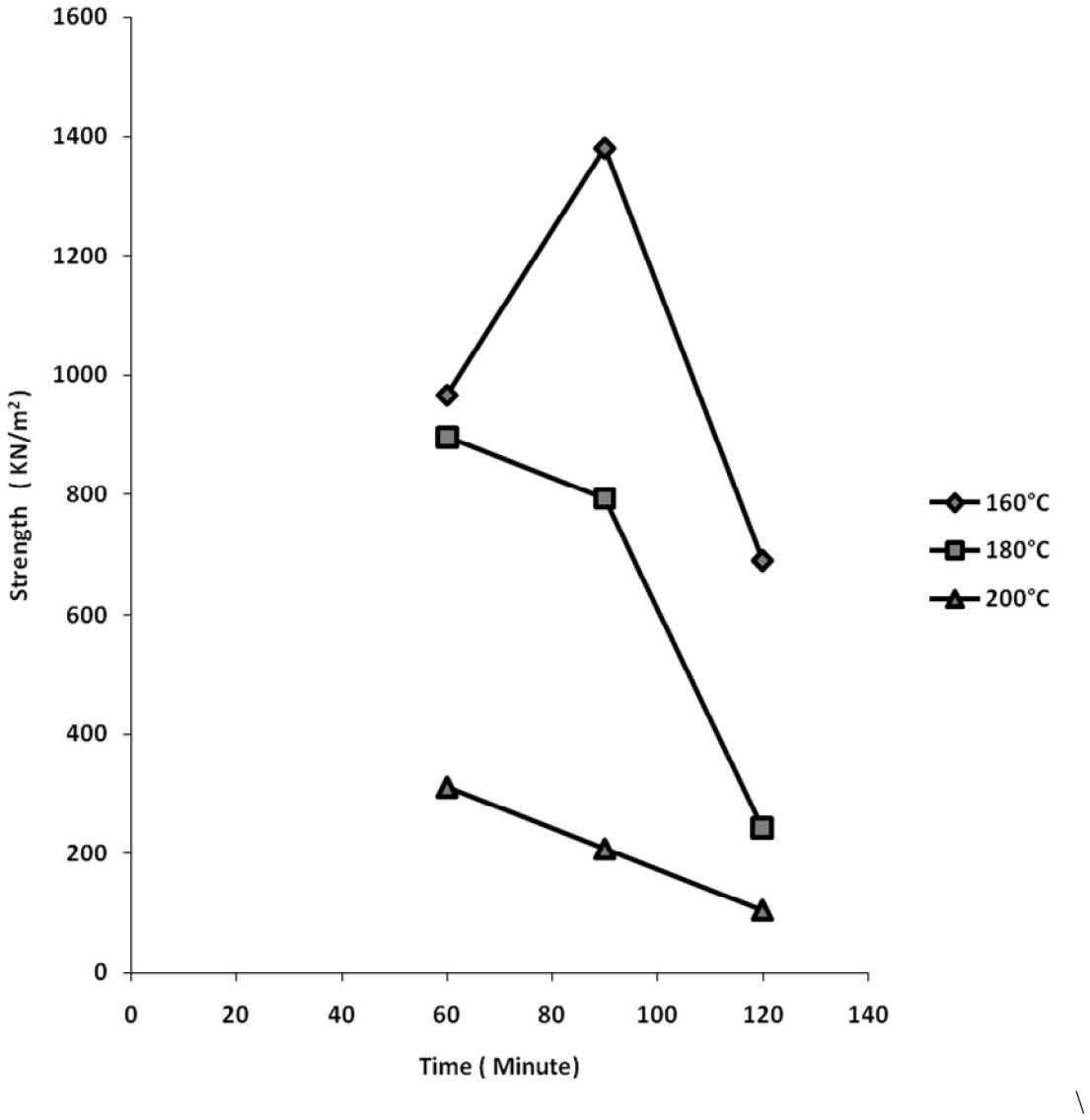


Figure 4.46: Optimum baked strength property developed at 7% *cissus populnea* , 0.5% cassava starch baked at a temperature of 160, 180 and 200^{0}C, baking time of 1 - 2 hours



Plate BI: As-cast surface finish of aluminium alloy casting utilizing 5% *cissus populnea* as binder for both mould and core



Plate BII: As-cast surface finish of aluminium alloy casting utilizing 5% *cissus populnea* as binder for both mould and core production baked at 160^0C for 1hour.



Plate BIII: As-cast surface of both the internal as well as the external walls of two aluminium alloy castings whose moulds as well as cores were made from a binder of 5% *cissus populnea*.



Plate BIV As-Cast internal surface of a grey iron casting utilizing a core made from 7% *cissus populnea* (binder) and baked at 160^0C at a baking time of 1.5hours.



Plate BV Sectioned As-Cast internal surface of a grey iron casting utilizing a core made from 7% *cissus populnea* (binder) and baked at 180^0C at a baking time of 1hour.



Plate BVI As-Cast internal surface of grey iron casting utilizing a core made from 7% *cissus populnea* (binder) and baked at 200^0C at a baking time of 1hour.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 COMPOSITION AND GRAIN FINENESS NUMBER OF BACITA SAND.

The chemical composition of Bacita sand has 94.5% silica (SiO_2), Al_2O_3 is 2.3%, ferric oxides 1.6% and impurities 1.5% Table A1. The high composition of silica is an indication that the sand is highly refractory and ideal for use as sand for making cores. Investigation of the properties of Bacita sand done by Sheidi and Ajuwa (2008) show that the fusion temperature of the sand is 1575^0C. This further confirms the suitability of the sand for foundry works. The grain fineness number (GFN) as calculated in Table A2 is 94.07. The shape of the sand is angular to sub angular (mixed). The grain fineness number of silica sand ideal for making cores for the casting of light alloys is 70-100 (Jain, 2003).

5.2 EFFECT OF *CISSUS POPULNEA* ON THE DEVELOPMENT OF BAKED TENSILE STRENGTH.

Cissus populnea used as binder for this research work lies between 3% - 7%. Binder percentages levels below 3% did not produce any baked strength. This was because the quantity of binder in the mix was not enough to coat the sand grains in order to hold the sand grains together after baking and was burned off before any baked strength could be developed. The bonds developed by this binder are by sharing of electrons. The fatty acids are made up of elements of carbon, hydrogen and oxygen Table D2. The interactions between the electrons when they are mixed up results into a strong bond based on the presence of oxygen which is strongly electronegative thus causing the other hydrogen attached to it to be slightly positively charged. This can lead to hydrogen bond

(Vlack, 1980). In addition, *Cissus populnea* belongs to the group of plants classified as vegetable gelatins. The gelatinous substance is obtained by the partial hydrolysis of cellulose. The cellulose bonds in the plant material is in such a manner that it gives it the gelatinous nature. A good percentage of the plant tissue is composed entirely of cellulose micro fibres.

Moisture in the core mix is removed by dehydration during the baking process. This process is similar to that of protein based binders developed by General Motors (Reich, 2005).

0.5% cassava starch was used during the moulding of the sand aggregate in order to impart the needed green strength to the core mix for easy handling (Achiv, 2001).

At 3% binder, varying water content level between 4 to 6% and baking the core mix aggregate at 160^{o}C, for 1hr, 1.5hrs and 2hrs, a maximum baked tensile strength of 517KN/m^2 was developed at a water content level of 6%, and baking time of 1.5hrs, (Figure 4.1). According to Ademoh (2009); Busby (1993); Titov and Stepanov (1982) cores with the above level of baked tensile strength are suitable for the casting of class II and III iron/ steel castings. Similarly, maintaining all parameters except the baking temperature which was increased to 180^{o}C, a maximum baked tensile strength of 380KN/m^2 at 6% water content level, and baking time of 1hr was developed, (Figure 4.2). This mix is suitable for casting class III iron and steel castings. Fixing again all parameters same but increasing the baking temperature to 200^{o}C, gave a maximum baked tensile strength of 311KN/m^2 at 5% water content level and baking time of 1hr, (Figure 4.3). This mix is suitable for making cores for the casting of magnesium alloys (Ademoh, 2009; Busby, 1993).

Increasing the binder content to 4% and varying the water content between 4% to 7% and baking time and temperature to between 1hr to 2hrs and 160^{o}C, 180^{o}C and 200^{o}C respectively had baked strength increased over that of 3% binder. This was because more binder was available at the contact points of the sand grains which enhanced better adhesion as compared to 3% binder.

Specifically, at 4% binder, water content was varied from 4% to 7%, baking time of between 1hr to 2hrs and baking temperature of 160^{o}C, a maximum baked tensile strength of 759KN/m^2 at water content level of 6% and baking time of 1.5hrs was developed, (Figure 4.4). This mix is suitable for making cores for the casting of class I iron/steel castings.

All other parameters being the same as for 4% binder, but increasing the baking temperature to 180^{o}C developed a maximum baked tensile strength of 414KN/m^2 at 5% water content level and baking time of 1hr, (Figure 4.5). According to Ademoh (2009), Busby (1993), this mix is suitable for making cores for the casting of class III iron/steel castings.

Increasing the baking temperature to 200^{o}C, all other parameters same as in different temperature ranges, a maximum baked tensile strength of 380KN/m^2 at 5% water content level and baking time of 1hr was developed, (Figure 4.6). This mix is suitable for making cores for the casting of class III and IV iron/steel alloys as well as magnesium alloy castings.

Increasing the binder content to 5% and varying the water content to between 4% to 8% and baking time and temperature to between 1hr to 2hrs and 160^{o}C, 180^{o}C and 200^{o}C respectively had baked strength increased over that of 3% and 4% binder.

When the binder content was fixed at 5% and water varied between 4% to 8% and baked for between 1hr and 2hrs at a baking temperature of 160^{o}C, a maximum baked tensile strength of 932KN/m^{2} and permeability no of 100 were obtained at 7% water content level and baked time of 1.5hrs, (Figure 4.7). This mix is suitable for making cores for the casting of class I iron/steel castings (Ademoh, 2009).

Still at 5% binder content, but increasing the baking temperature to 180^{o}C, a maximum baked tensile strength of 466KN/m^{2} and permeability number of 93 was developed at 7% water content and at a baking time of 1hr, (Figure 4.8). This mix is suitable for making cores for the casting of class III iron/steel castings, copper/bronzes, non intricate aluminium and magnesium alloy castings (Ademoh, 2009; Busby, 1993).

At 5% binder content, baking temperature of 200^{o}C, a maximum baked tensile strength of 431KN/m^{2} was developed at 6% water content level and at a baking time of 1.5hrs, Figure 4.9. This mix is suitable for making cores for the casting of copper/bronzes, non intricate aluminium and magnesium alloy castings (Ademoh, 2009; Busby, 1993).

Generally, a fixed value of 5% binder with varying water, baking temperature and time produced cores that developed baked tensile strength values that are suitable for the casting of aluminium and other non ferrous metals.

At 6% binder level, water content was varied between 4 to 8% and baking temperature and time between 160^{o}C, 180^{o}C and 200^{o}C and 1hr to 2hrs respectively, the baked tensile strength of cores developed was significantly higher than those whose binder content was 3, 4 and 5% respectively. As mentioned earlier, the binder in contact with sand grains was higher in this mix as compared the previous ones whose binder content was lower in the mix.

Specifically, at 6% binder content and baking temperature of 160^{o}C, a maximum baked tensile strength of 1242KN/m^2 was developed at 7% water content level and at a baking time of 1.5hrs, (Figure 4.10). This mix is suitable for making cores for the casting of class I iron/steel alloys. Generally, the baked tensile strength developed from each of the core mix baked at this temperature (160^{o}C) and baking time of 1hr to 2hrs at water content level of between 4 to 8% could be used for casting different classes of ferrous and non ferrous alloys (Ademoh, 2009).

Maintaining 6% binder content, but increasing the baking temperature to 180^{o}C, a maximum tensile strength of 863KN/m^2 was developed at 7% water content level and at a baking time of 1hr, (Figure 4.11). This mix is suitable for making cores for the casting of class I iron/steel castings. Each of the various mixes that were baked at this temperature (180^{o}C) for 1hr and 1.5hrs could be used for the casting of different classes of ferrous and non ferrous alloys.

When the temperature was increased to 200^{o}C, but binder content still at 6%, a maximum baked tensile strength of 483KN/m^2 was developed at 7% water content and at a baking temperature of 1hr, (Figure 4.12). This category of core mix is suitable for the casting of class III iron/steel castings, copper/bronze castings, non intricate aluminium castings and magnesium castings, Ademoh (2009). The baked tensile strength developed from each of the core mix baked at this temperature (200^{o}C) and baking time of 1hr to 2hrs at water content level between 4 to 8% could be used for casting different classes of alloys (Ademoh, 2009; Busby, 1993).

At 7% binder level, water was varied between 4 to 8% and baking temperature and time between 160, 180 and 200^{o}C and 1 to 2hrs respectively, a higher baked tensile strength was developed as compared to 3, 4, 5 and 6% binder content levels.

Specifically, at 7% binder level, 7% water content, baking temperature of 160^{o}C and baking time of 1.5hrs, a maximum baked tensile strength of 1380KN/m^2, baked compression strength of 3225.75KN/m^2 and permeability no of 125 were developed respectively Appendix B1. Figure 4.13 shows the values of the baked tensile strength plotted against time. The green compression strength for this mix was 60.72KN/m^2. Appendix D1 show various values of baked tensile strength developed using different local binders. *Cissus populnea* is the third highest on this table. This further confirms the suitability of this material as binder for core making. The baked tensile strength developed from each of the core mix baked at this temperature (160^{o}C) and baking time of 1 to 2hrs at water content level between 4 to 8% could be used for casting different classes of ferrous alloys.

Still at 7% binder, but baking temperature of 180^{o}C, a maximum baked tensile strength of 897KN/m^2 and baked compression strength of 3105KN/m^2 were developed at 7% water content and baking time of 1hr, (Figure 4.14) and Appendix B1. This core mix is suitable for the casting of class I iron/steel castings.

At 7% binder content and baking temperature of 200^{o}C, a maximum baked tensile strength of 518KN/m^2, baked compression strength of 1690KN/m^2 and a permeability no of 110 were developed at 5% water content level at baking time of 1hr. Green compression strength of 56.58KN/m^2 was also developed. Figure 4.15 shows the graph of tensile strength values plotted against time. The cores in this category are suitable for the

casting of class II and III iron/steel castings, copper/bronze castings, intricate and non intricate aluminium castings and magnesium alloy castings (Ademoh, 2009); (Busby 1993); (Titov and Stepanov, 1982).

5.3 EFFECT OF WATER CONTENT ON THE DEVELOPMENT OF BAKED TENSILE STRENGTH.

At 3% binder and baking time varied between 1 to 2hrs, 6% water content developed the highest baked strength of 517KN/m^2 at a baking temperature of 160^{o}C and baking time of 1.5hrs, (Figure 4.16). At a baking temperature of 180^{o}C, 6% was still the optimum water content which developed a baked tensile strength of 380KN/m^2 at a baking time of 1hr, (Figure 4.17); while at 200^{o}C, the optimum water content was 5% which developed a baked tensile strength of 311KN/m^2 at a baking time of 1hr, (Figure 4.18).

At 4% binder and baking time varied between 1 to 2hrs, 6% water content developed the highest baked strength of 759KN/m^2 at a baking temperature of 160^{o}C and a baking time of 1.5hrs, (Figure 4.19) while 5% was the optimum water content level that developed the highest baked tensile strength of 414KN/m^2 and 380KN/m^2 respectively at a baking time of 1hr each and baking temperature of 180 and 200^{o}C respectively, (see Figures 4.20 and 4.21).

At 5% binder content, 7% water content developed the highest baked tensile strength of 932KN/m^2 at baking time of 1.5hrs and baking temperature of 160^{o}C. The permeability no of 100 was also obtained. A baked tensile strength of 466KN/m^2 was developed at a baking time of 1hr and baking temperature of 180^{o}C and a permeability number of 93, Figures 4.22 and 4.23 respectively show the recorded baked tensile strength values at

160^0C and 180^0C. 6% water content developed a maximum baked strength of 431KN/m^2 at baking time and temperature of 1.5hrs and 200^{o}C respectively, (see Figure 4.24).

At 6% binder content, 7% water content developed highest baked tensile strength values of 1242, 863 and 483KN/m^2 at baked temperatures of 160, 180 and 200^{o}C and baking time of 1.5hrs and 1hr respectively; (see Figures 4.25, 4.26, and 4.27).

At 7% binder content, 7% water content developed the highest baked tensile strength of 1380 and 897KN/m^2 respectively at baking temperatures of 160 and 180^{o}C at baking times of 1.5hrs and 1hr respectively, (see Figures 4.28 and 4.29). 5% water content developed a baked tensile strength of 518KN/m^2 at a baking temperature of 200^{o}C and a baking time of 1hr, (Figure 4.30).

In all the mixes employing all the binder content levels, baking temperatures and baking time, the baked tensile strength values dropped when water content was increased to 8% and beyond. This was because all the moisture in the mould could not be removed as a result of high concentration of water in the mix. Generally, 4 to 8% water content level was ideal for producing cores. However, the optimum water content in the mix was 7% at 7% binder and a baking temperature of 160^{o}C, (Figure 4.28).

5.4 EFFECT OF BAKING TIME ON DEVELOPING BAKED TENSILE STRENGTH.

Generally, the cores were baked at 160, 180 and 200^{o}C for 1hr to 2hrs varying the time interval at 30 minutes. At 4% water content, baking temperature of 160^{o}C, a baked strength of 552KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs, (Figure 4.31). At 180^{o}C, a baked strength of 569KN/m^2 was developed at 7%

binder content level and a baking time of 1hr, (Figure 4.32), while at 200^{o}C, a baked strength of 449KN/m^2 was developed at 7% binder and baking time of 1hr, (Figure 4.33). At 5% water content, baking temperature of 160^{o}C, a baked strength of 759KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs, (see Figure 4.34). At 180^{o}C, a baked strength of 656KN/m^2 was developed at a binder content level of 7% and baking time of 1hr, (Figure 4.35), while at 200^{o}C, a baked strength of 518KN/m^2 was developed at a binder content level of 7% at a baking time of 1hr, (Figure 4.36).

At 6% water content, baking temperature of 160^{o}C, a baked strength of 932KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs, (Figure 4.37). At 180^{o}C, a baked strength of 828KN/m^2 was developed at a binder content level of 7% and baking time of 1hr, (Figure 4.38), while at 200^{o}C, a baked strength of 449KN/m^2 was developed at a binder content level of 6% at a baking time of 1hr, (Figure 4.39).

At 7% water content, baking temperature of 160^{o}C, a baked strength of 1380KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs, (Figure 4.40). At 180^{o}C, a baked strength of 897KN/m^2 was developed at a binder content level of 7% and baking time of 1hr, (Figure 4.41), while at 200^{o}C, a baked strength of 483KN/m^2 was developed at a binder content level of 6% at a baking time of 1hr, (Figure 4.42).

At 8% water content, baking temperature of 160^{o}C, a baked strength of 897KN/m^2 was developed at a binder content level of 7% at a baking time of 1.5hrs, (Figure 4.43). At 180^{o}C, a baked strength of 621KN/m^2 was developed at a binder content level of 7% and baking time of 1hr, (Figure 4.44), while at 200^{o}C, a baked strength of 380KN/m^2 was developed at a binder content level of 6% at a baking time of 1hr, (Figure 4.45).

Generally, an optimum baking time of 1.5hrs developed a baked strength of 1380KN/m^2 at 7% binder, 7% water at a baking temperature of 160^{o}C, (Figure 4.40).

5.5 EFFECT OF BAKING TEMPERATURE ON DEVELOPING BAKED TENSILE STRENGTH.

Cores that were baked below a temperature of 160^{o}C developed weak baked strength because the water in the mix was yet to be fully evaporated. Cores that were baked beyond a baking temperature of 200^{o}C had started to char, thereby developing weak baked strength.

For this research, baking temperature of between 160 and 200^{o}C developed baked strength that could be used for the casting of different alloys with different section thicknesses. An optimum baking temperature of 160^{o}C developed the maximum baked tensile strength of 1380KN/m^2 at a binder content of 7% and water content of also 7%, and a baking time of 1.5hrs, (see Figure 4. 46).

5.6 PERMEABILITY

Permeability and strength are two of the most essential properties of sand. Their values must be as high as possible, Jain (2003). Permeability numbers that were obtained at 7% *cissus populnea* Tables B1 and B2 were 125 and 110 at 7% and 5% water content respectively. The acceptable range for the casting of cast irons and its alloys is 100-130, (Ademoh, 2009); (Jain, 2003). This further confirms that this mix is suitable for the casting of cast iron alloys.

5.7 STATISTICAL DESIGN AND DEVELOPMENT OF MATHEMATICAL MODEL EQUATION FOR *CISSUS POPULNEA*

5.7.1. Model for Prediction of Baked Tensile Strength

The test results were recorded against the standard order of sequence as shown in Table 5.1

Table 5.1: **Complete matrix including interactions with effects calculated**.

Run No.	Main effects			Interactions effects				Response
	T_b	w_b	t_b	$T_b w_b$	$T_b t_b$	$w_b t_b$	$T_b w_b t_b$	X KN/m^2
1	-1	-1	-1	+1	+1	+1	-1	518
2	+1	-1	-1	-1	-1	+1	+1	345
3	-1	+1	-1	-1	+1	-1	+1	966
4	+1	+1	-1	+1	-1	-1	-1	311
5	-1	-1	+1	+1	-1	-1	+1	485
6	-1	+1	+1	-1	-1	+1	-1	790
7	+1	-1	+1	-1	+1	-1	-1	138
8	+1	+1	+1	+1	+1	+1	+1	104
Effect	-465.3	+171.3	-155.8	-205.3	-51.3	-35.8	38.3	457.1

Table 5.2: Analysis of variance to identify factors influencing baked tensile strength of cores.

Source	Sum of squares (SS)	Degree of freedom (Df)	Mean square (Ms)	F value
Model				
T_b	433008.2	1	433008.2	120.8
w_b	58687.4	1	58687.4	16.4
t_b	24258.1	1	24258.1	13.5
$T_b w_b$	84255	1	84255	23.5
Residuals	10752.8	3	3584.3	
Total		7		

From the matrix including interactions with effects calculated, Table 5.1, the main effects for the development of baked tensile strength in order of ranking are baking temperature T_b, percentage weight of binder w_b, and baking time t_b. The strongest interaction effect is baking temperature and percentage of binder, $T_b w_b$

The model equation for the prediction of baked tensile strength 3.2 is brought in here and expressed as:

$X = \beta_0 + \beta_1 T_b + \beta_2 w_b + \beta_3 T_b w_b + \beta_4 t_b + \beta_5 w_b t_b + \beta_6 T_b t_b + 3 T_b w_b t_b$ ---------- (3.2).

Substituting the values of β_0 = the intercept, and β_1 to β_7 = the model coefficient for the input factor,

$X = 457 - 232.7 T_b + 85.6 w_b - 77.9 T_b w_b - 102.6 t_b - 25.6 w_b t_b - 17.8 T_b t_b + 19.1 T_b w_b t_b$ --------- 4.1

Where T_b = Baking temperature

w_b = percentage weight of binder

t_b = baking time

Substituting the coded values of variables for each experimental number, the predicted values were calculated and tabulated in Table 5.3

From the ANOVA table identifying factors influencing baked tensile strength of cores, Table 5.2, and the F value (calculated) are compared with Fcritical. F distribution critical values for degrees of freedom (1, 7), the values are above 5.32 for 95% and above 11.26for 99% confidence (Miller and Freund, 2001). Thus from the Table, 5.2, it can also be observed that the factors that have the strongest influence are baking temperature with coefficient of 120.8 followed by percentage weight of binder with coefficient of 16.4 and

then baking time with coefficient of 13.5. It can therefore be concluded that baking temperature had the strongest influence on the developed baked tensile strength of core

Table 5.3: Comparison of the Actual baked tensile strength with the predicted values.

Run No	Tensile strength (KN/m^2)	
	Actual	Predicted
1	518	566
2	345	330.8
3	966	982.7
4	311	359.2
5	485	486.2
6	790	723.6
7	138	102.8
8	104	105.4

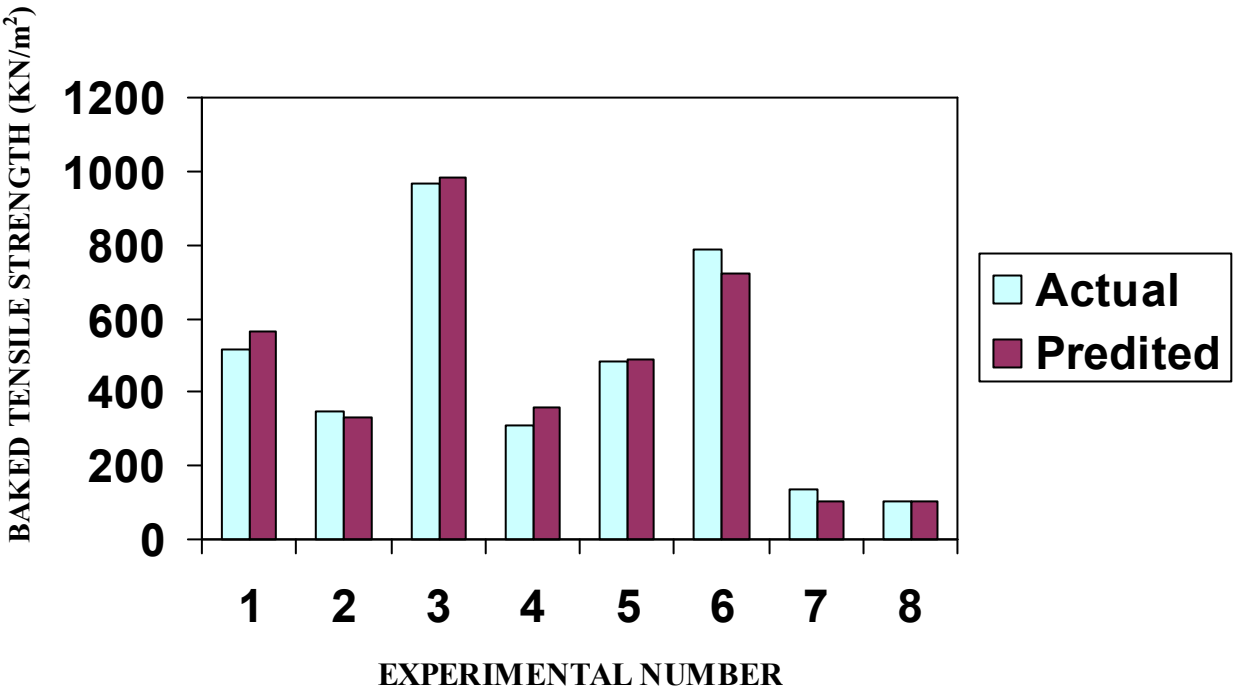


Figure 5.1 Actual values with predicted values

According to Miller and Freund (2001), the coefficient R should fall between -1 and +1. For this experimental model, the value of R has been calculated to be +0.99. From figure 5.1 the experimental values are in close agreement with the calculated ones which goes to confirm the adequacy and reliability of the equation to predict the baked tensile strength of cores.

5.8 TRIAL CASTINGS

Cores bonded with 5% *cissus populnea* with 7% water concentration in the mix and 0.5% cassava starch and baked for 1hour at a baking temperature of 180^0C were used in producing test castings for aluminium alloy. The mould for the casting was also produced using the same sand mix and baked in the oven to remove moisture. On opening of the

mould when the casting cooled to room temperature, it was observed that the casting surface finish was quite good and the collapsibility was also very good. Plates BI to BIII show the details of the casting surface finish as well as the surface finish of the cored surface.

Similarly, cores bonded with 7% *cissus populnea* with 7% water concentration and 0.5% cassava starch and baked for 1.5hours at a baking temperature of 160^0C were used in producing test castings for grey cast iron. The cored surface of the castings as shown in Plate BIV had very good surface finish as well as very good collapsibility. The same concentration of 7% binder that was baked at 160^0C was baked 180^0C and 200^0C for 1 hour in each case and was used in producing test castings as shown in Plates BV and BVI. The as-cast surface finish of the cored surface of cores using this mix was good. They also had good collapsibility. There was no trace of porosity and blow holes on sectioned parts of the casting which confirmed the absence of these defects on the castings.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions have been deduced from the use of *cissus populnea* as a binder for core production.

1. Baked tensile strength was developed when binder content in the mix was 3%. Below this level, the core mix could not be moulded. At binder content of 7%, baked strength of about 1380KN/m^2 was developed suggesting that as the binder content in the mix increases, higher baked tensile strength could be developed.
2. Baking temperatures of between 160^0C and 200^0C were adequate for baking of these cores. Baking temperatures below 160^0C produced cores that were weak in baked tensile strength. This could be because moisture was still present in the cores. Baking temperatures beyond 200^0C also produced weak cores because beyond this temperature, the core had started to burn.
3. The water content that developed good baked strength was between 4 and 8%. Below 4% water content, the mix could not be rammed and beyond 8% water in the mix, moisture could not be completely evaporated during the drying process therefore resulting in cores with very weak baked strength.

4 Baking time of between 1 to 2 hours developed adequate baked strength. Below 1 hour, the core still had moisture in them and beyond 2 hours, the core had started to burn.

5. Permeability numbers of between 93 and 125 were obtained in all the tested cases suggesting that the cores developed using this binder have good foundry properties

6 Green compression strength of between 56.58KN/m^2 and 60.72KN/m^2 was developed suggesting that these cores could be handled in the green state without disintegration.

7. There was no indication that fumes were generated in the process of core setting suggesting that baked tensile strength was developed by the process of dehydration.

8. A maximum baked compression strength of 3225.75KN/m^2 was developed at 7% binder, 7% water, 0.5% cassava starch and 85.5% sand and baking temperature of 160^0C and baking time of 1.5hours. This suggests that the cores can accommodate the weight of the mould mass and the buoyancy effect of molten metal.

6.1.2 Contribution to knowledge

(a) It was established that *cissus populnea* developed properties that are good enough to be used as binder for production of foundry cores. The maximum baked strength value of 1380KN/m^2 and compression strength of 3225.75KN/m^2 was established which competes favourably with other local binders and in some cases surpass the existing ones.

(b) *Cissus populnea* developed baked strength properties that are adequate for the casting of non ferrous alloys such as aluminium, brass, bronze and magnesium.

(c) *Cissus populnea* developed baked strength properties that are equally adequate for the casting of iron and steel castings.

(d) A universal binder has been established.

(e) The collapsibility of cissus populnea is excellent when compared with the existing ones

6.2 RECOMMENDATIONS

1 The strands of *cissus populnea* are fibrous in nature suggesting that they could be used as laminates for producing automotive and other industrial spare parts.

2 Government should look at the possibility of banning the importation of binders for foundry work so that the potentials of this new material produced could be exploited.

3 The composition 7% binder, 7% water, 0.5% cassava starch and the balance being sand could be used to make cores for steel castings.

REFERENCES

Achibald, J.A. (1994). Benchmarking the No Bake Binder Systems. *Modern Castings,* 11(4):1-3.

Achiv, F.M; Aponbiede, O and Hassan S.B. (2010). Mechanical Properties of Sand Cores bonded with 5% *Cissus populnea* for Production of Aluminium Castings. Journal of Metallurgy and Materials Engineering, 5(1): 62-67.

Achiv, F.M. (2001). Suitability of Locally Sourced Materials as Mould and Core Coatings for Grey Iron Castings. Unpublished M.Sc. Thesis. Department of Metallurgical Engineering, Ahmadu Bello University, Zaria, Nigeria.

Ademoh, Nuhu Ali (2010). Evaluation of the tensile strength of foundry cores made with hybridized binder composed of Neem oil and Nigerian gum arabic. *International Journal of the Physical Sciences* Vol. 5(5): 557-563.

Ademoh, Nuhu Ali and Abdullahi, Ahmed Tijani (2008). Evaluation of Mechanical properties of Expendible Sand Cores Bonded with the Nigerian Gum Arabic Grade 4. *American-Erusian Journal of Scientific Research* 3 (2): 199-204.

Ademoh, Nuhu Ali (2008). Evaluation of the Foundry Properties of River Niger Sand Behind Ajaokuta Steel Company Limited, Ajaokuta, Nigeria. *American-Eurasian Journal of Scientific Research,* 3 (1): 75-83.

Ali,Y; Hanna, M. A; Cuppett, S. L; (1995). Oils. *Journal of American Oil Chemical Society*, 72, 1557-1564.

American Association of State Highway and Transportation Officials, (AASHTO)

(1986): Standard Method of Test, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate, AASHTO Designation: T104, Part II Tests, 14th Edition.

American Foundry men's Society; (1991). Alternative Utilization of Foundry Waste

Sand. *Final Report (Phase I)* prepared by American Foundrymen's Society Inc. for Illinois Department of Commerce and Community Affairs, Des Plaines, Illinois

Andrea Ferrero, Marcello Badiali, Richard Schreck, June-Sang Siak and William

Whited, (1998). New binder for casting cores: An industrial application to safety suspension parts. *SAE Technical Paper Series*, International Congress and Exposition, Detroit, Michigan, February, 23-26.

Aponbiede, O. (2004). Comparative study on Soya bean oil and rubber seed oil as core binders in Foundry application. *Nigeria Society of Engineers Technical Transaction* 39 (4): 44-46

Aponbiede O, (2000). Development of Oil Sand Cores using Local Vegetable Oils. Unpublished PhD Thesis, Metallurgical Engineering Department, Ahmadu Bello University, Zaria, Nigeria.

Aponbiede O and Ochuokpa E. O, (2008). Comprehensive Foundry Technology Laboratory Manual. Handbook written for 400level Metallurgical and Materials Engineering Laboratory Work. Pp 11-12, 15.

Applewhite, T. H, Kirk-Othmer, (1980). *Encyclopedia of Chemical Technology;* Third edition, John-Wiley and Sons; NewYork, Vol.9: 795-811.

Bates, C. E; Wirnardi, L; Littleton, H. (2008). Variables affecting Gas-Evolution Rates from Cores in contact with Aluminium". *Foundry Management and Technology*, 8: 30-41.

Bates, C. E. (2007). Core and Mould Gas Evolution: Porosity in Castings. *Foundry Management and Technology,* 6(25): 17

Bates, C.E. (2004). Advances in Core Making. *Foundry Management and Technology*, 4: 2 – 3.

Bates, C. E. (2003). Putting GMBOND to the Test. *Foundry Management and Technology*, 9 (30): 12.

Bauman, B.V and Isakhanyan, N. T (1989). Moulding Materials. In: Mikhailov, A.M.*Metal Casting*, Mir Publishers Moscow, p. 78,

Brooke Lindsay and Evans Harry, (2009). "Lighten up" *a mass reduction report*, Automotive Engineering International, Vol. 3: pp16-20.

Buléon, A; Colona, P; Planchat,V; and Ball, S; (1998). "Starch granules": structure and biosynthesis, *Int. J. Biol. Macromol*. Vol.23: 85-112.

Busby, A. D. (1992). Phenolic ester process – the past, present and future. The American

Foundry men Society Congress, Chicago, *AFS Transactions* 93 (172): 621-633.

Busby, A.D. (1993). Recent Development in Binder Technology, Institute of British Foundry men, 9th annual conference, *Castion York Foundry* pp13-38.

Campbell, J. (1997). "Castings", Butterworth-Heinemann, P. 34

Campbell, John (2003). Castings, Butterworth-Heinemann, ISBN 9780750647908, P.277.

Carney, Dan (2008). Advanced Metals gaining momentum, *Automotive Engineering International,* Vol.8: 44-47.

Carter, S.F. Evans, W.J. Harkness, J.C. Wallace, J.F. (1979). Factors Influencing the Formation of Pinholes in Grey and Ductile Irons.*Transactions AFS,* Vol. 87, P. 245.

Cobos, L. (1996). Recent Studies Comparing Core making Processes. *Modern Casting*, March1.

Collins, R. J. and Ciesielski S. K. (1994). Recycling and Use of Waste Materials and By-Products in Highway Construction. National Cooperative Highway Research Program Synthesis of Highway Practice 199, Transportation Research Board, Washington, DC.

Degarmo, E. Paul. Black, J. T. Kohser, Ronald A. (2003). *Materials and Processes in Manufacturing* (9th ed.), Wiley, ISBN 0-471-65653-4 pp 311- 313

Fayomi, O.S.I, Ajayi, O.O, Popoola A.P.I. (2011). Suitability of Local Binder Compositional Variation on Silica Sand for Foundry Core-making. *International Journal of the Physical Sciences,* vol. 6(8): 1940-1946.

Foseco, (2008). *Committed to foundries*. Retrieved on June 21, 2009, from http://www.foseco.com/

Foseco, (2004). *Committed to foundries*. Retrieved on June 21, 2009, from http://www.foseco.com/

Gehm,Ryan (2009). Metal Matrix Composite Brake Drum 45% lighter than Cast Iron. *Automotive Engineering International*, Vol. 12: 23-24.

Giese, C. and Thiel, J. (2008). *Expansion Characteristics of silica sands.* Retrieved on June 21, 2009 from UNI's metal casting centre.mht http://www.mcc.uni.edu/

Giese, C. and Thiel, J. (2008). *UNI's metal casting centre ceramic particles*. Retrieved on June 21, 2009 from http://www.mcc.uni.edu/

Goering, C.E. Schwab, A. W. Daugherty, M.J. Pryde, E.H. Heakin A. J. (1982). *Trans. ASAE* 25. 1472-1477 and 1483.

Gunstone, F.D. Harwood, J.L. Padley, F. B (1994). Lipid Handbook, second edition; Chapman and hall, London pp 17-23

Ham, R. K. Boyle,W. C. Engroff, E. C. and Fero, R. L. (1989). Determining the Presence of Organic Compounds in Foundry Waste Leachates. *Modern Casting*. American Foundrymen's Society, August.

Heine W. Richard, Loper R. Carl and Rosenthal C. Phillip (2004. *Principles of Metal Casting*. Tata McGraw – Hill Publishing Co. Ltd New Delhi, India, pp. 123 – 149.

Ireland Eric, Chang Ken and Krober Jorg; (2002): American Foundry Men's Society (AFS) *Transactions* pp. 1 – 2.

Jain, P.L. (2003). *Principles of Foundry Technology*. Fourth Edition, Tata McGraw – Hill Publishing Co. Ltd. New Delhi, India pp.63, 85 – 91, 104 -151.

Javed, S. and Lovell, C. W. (1994). Use of Foundry Sand in Highway Construction. Joint Highway Research Project No. C-36-50N, Department of Civil Engineering, Purdue University, Purdue, USA.

Khanna, O.P. (2005). *A Textbook of Foundry Technology*. Dhanpat Rai Publications (P) Ltd, New Delhi, India pp. 152 – 177.

Knothe, G. Dunn, R. O. and Bagby, M. O (1995): ''the use of Vegetable Oils and their Derivatives as alternative Diesel Fuels'' Fuels and Biomass, American Chemical Society, Washington D.C.

Kozlov, L. Ya (1989). Preparation of Moulds and Cores. In: Mikhailov, A.M. *Metal Casting*, Mir Publishers Moscow, pp. 108 - 110.

Lemon, Peter Herbert; Richard B. R; Railton, Jeffrey David, Ludlam, Peter Raymond and Reynolds, Timothy John; (1983). Foundry Moulds and Cores - UK Patent no EP0086615.mht.

Mandal A, and Roy P. (2006). Modeling the compressive strength of molasses- cement sand system using design of experiments and back propagation neural network. *Journal of Materials Processing Technology*, volume 180, issues 1-3 1st December: 167-173.

Miller,I, and Freund, J.E. (2001): *Probability and Statistics for Engineers*, Prentice Hall India Ltd., India, pp 125-140.

MNR; (1992): Mineral Aggregate Conservation - Reuse and Recycling. Report prepared by John Emery Geotechnical Engineering Limited for Aggregate and Petroleum Resources Section, Ontario Ministry of Natural Resources, Queen's Printer for Ontario, February.

MOEE; (1993): Spent Foundry Sand - Alternative Uses Study. Report prepared by John

Emery Geotechnical Engineering Limited for Ontario Ministry of the Environment and Energy and the Canadian Foundry Association, Queen's Printer for Ontario, July.

Moll, N. (1987): Advanced Mouldable Foam Eliminates Carbon Defects in Evaporative Pattern Castings. *Modern Castings* p. 37.

Naro, R. L. Porosity. *Modern Castings.* April, 2002. pp. 41-44

Naro, R.L; (2000). Defects in Grey and Ductile Iron Castings. (file://E:\porosity.htm. Retrieved on September 17, 2009.

Naro, R. L; (1999): Porosity Defects in Iron Castings from Mould Metal Interface Reactions, *AFS Casting Congress*. March 15.

Olakanmi, E. O and Arome, A.O. (2009) Characterisation of the Core Binding Properties of Fatty-Based Oils. *International Journal of Physical Sciences* Vol. 4 (11): pp.623-629.

Ontario Ministry of Transportation; (1996): Resistance of Fine Aggregate to Degradation by Abrasion in the MicroDuval Apparatus, LS-619, Ontario Ministry of Transportation, Ontario, Canada.

Oregon State University; (2007): Learning Food Resource. Retrieved on March 8, 2008

from http://food.oregonstate.edu/ Oregon State University Corvallis, October 24.

Rabbii, Ahmad; (2001): Sodium Silicate Binder as an Inorganic binder in Foundry Industry. *Iranian Polymer Journal*, 10 (11): 253-257.

Rahmoeller, K. M; (1993): "Mould binder decomposition" prime sources of cast iron gas defects; Retrieved on April 14, 2009 from http://www.thefreelibrary.com/mould

Rao, T. V. (2003), *Metal Casting: Principles and Practice*, New Age International, ISBN 9788122408430 p 15.

Reich, David; (2005): Laempe + Reich Corp. Transville Alabama, USA. A USA Environmental Protection Agency – Inorganic Binder Laempe Beach box process using Laempe + kuhs binders, October USEPA meeting on innovative binders for iron and steel foundries.

Sarkar, A.D; (1967): *Mould and Core Material for Steel Foundry*, Pergamon Press London, pp. 1 – 2.

Scarber, Jr. P, and Bates, C. E. (2006): "Simulation of Core Gas Production During mould Fill". *AFS copyright*.

Sheidi, H.M. and Ajuwa, C.I. (2008). Investigation on Properties of River Sand for Sound Casting, River Niger at Bacita Nigeria. *Journal of Engineering and Applied Sciences* 3 (3): pp. 214-216.

Sosnenko, N. M; (2001): *General Technology of Casting Production,* Mir Publishers Moscow, p 306.

Stefanescu, Doru Michael, (2008); *Science and Engineering of Casting Solidification* 2nd Edition Springer ISBN 9780387746098 p 69.

Vlack, Van (1980). Material Science for Engineers. World Student Edition, 8th Printing Pp 34-35.

Wirnadi, L; Littleton H. E; Bates, C. E; (2005): New Technique for measuring

permeability of cores made from various sands, binders, additives, and castings. *AFS Transactions* Vol. 113: 393-406.

Yu, Kuang-Oscar (2002), *Modeling for casting and solidification processing,* CRC Press, ISBN 9780824788810 p 305.

APPENDIX A

Appendix A1: Chemical analysis of Bacita foundry sand

S/No	Compound	Percentage (%)
1	Al_2O_3	2.30
2	SiO_2	94.50
3	Fe_2O_3	0.90
4	CaO	0.12
5	TiO_2	0.290
6	K_2O	0.26
7	V_2O_5	0.10
8	Cr_2O_3	0.29
9	MnO	0.09
10	NiO	0.04
11	CuO	0.11
12	ZnO	0.002
13	SrO	0.04
14	ZrO_2	0.45
15	RuO_2	0.51
16	MgO	0.06
17	Na_2O	0.01

Appendix A2: Sieve analysis of Bacita foundry sand

S/No	Aperture (μm)	Sieve No	Weight Retained (g)	% of Retained	Cumulative Weight	Product
1	1400	14	0.18	0.18	0.18	000
2	1000	18	0.24	0.24	0.42	3.36
3	710	25	0.30	0.30	0.72	5.40
4	500	35	0.22	0.22	0.94	5.50
5	355	45	0.38	0.38	1.32	13.30
6	250	60	8.70	8.70	10.02	391.50
7	180	80	26.44	26.44	36.46	1586.40
8	125	120	34.62	34.62	71.08	2769.60
9	90	170	15.77	15.77	86.85	1892.40
10	63	230	4.75	4.75	91.60	807.50
11	-63 (pan)	-230	8.40	8.40	100	1932
Total			100			9406.96

GFN = $\frac{\text{Total Product}}{\text{Total Weight Retained}}$

$\frac{9406.96}{100}$ = 94.07 AFS

GFN = 94.07

Colour: Light Brown

Shape: Angular to Sub Angular

APPENDIX B

Table B1 **Strength in KN/m^2 of 3% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C.**

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	207	276	173
5	242	414	207
6	310	517	276
7	Too wet	Too wet	Too wet

Table B2 **Strength in KN/m^2 of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C.**

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	242	414	207
5	276	621	242
6	345	759	289
7	Too wet	Too wet	Too wet

Table B3 **Strength in KN/m^2 of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C.**

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	311	483	248
5	414	621	362
6	449	828	421
7	518	932	485
8	390	587	259

Table B4 **Strength in KN/m^2 of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C.**

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	345	518	311
5	569	690	414
6	656	897	500
7	794	1242	621
8	483	625	380

Table B5 **Strength in KN/m^2 of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 160^{o}C.**

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	449	552	414
5	638	759	483
6	828	932	687
7	966	1380	790
8	756	897	580

Table B6 Strength in KN/m^2 of 3% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	276	242	138
5	293	276	224
6	380	362	241
7	Too wet	Too wet	Too wet

Table B7 Strength in KN/m^2 of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	293	207	69
5	414	382	207
6	362	276	120
7	311	224	118

Table B8 Strength in KN/m^2 of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	345	276	104
5	414	351	198
6	449	380	224
7	466	449	242
8	380	311	130

Table B9 Strength (KN/m^2) of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^oC.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	449	380	155
5	611	507	245
6	701	621	306
7	863	673	359
8	552	449	207

Table B10 Strength in KN/m^2 of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 180^oC.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	569	527	173
5	675	578	311
6	828	690	367
7	897	794	397
8	621	483	256

Table B11 Strength in KN/m^2 of 3% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	270	259	121
5	311	293	207
6	276	207	173
7	Too wet	Too wet	Too wet

Table B12 Strength in KN/m^2 of 4% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	276	204	127
5	380	345	243
6	328	293	207
7	311	242	190

Table B13 Strength in KN/m^2 of 5% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	380	345	179
5	397	390	224
6	414	431	245
7	345	311	138
8	311	276	69

Table B14 Strength in KN/m^2 of 6% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	397	345	224
5	414	380	242
6	449	414	276
7	483	451	298
8	380	311	104

Table B15 Strength in KN/m^2 of 7% *Cissus populnea* 0.5% cassava starch bonded cores with varying water content baked at 200^{o}C.

% Water	1hr	1.5 hrs	2hrs
3	Not moulding	Not moulding	Not moulding
4	449	380	190
5	518	414	207
6	414	362	173
7	311	207	104
8	242	190	86

APPENDIX C

Table C1: Properties of cores made with 7% binder, 7% water, 0.5% cassava starch and 85.5% sand.

Permeability no	Green Compression Strength (KN/m^2)	Baked Compression Strength (KN/m^2)	Baking Temperature (^0C)	Baking Time (Hours)
125	60.72	3225.75	160^0C	1.5
125	60.72	3105	180^0C	1

Table C2: Properties of cores made with 7% binder, 5% water, 0.5% cassava starch and 87.5% sand.

Permeability no	Green Compression Strength (KN/m^2)	Baked Compression Strength (KN/m^2)	Baking Temperature (^0C)	Baking Time (Hours)
110	56.58	1690	200	1

APPENDIX D

Table D1: Proximate analysis of *Cissus populnea*.

Sample	% Protein	% Ash	% Moisture	% Lipid	% Fibre	% CHO
A	3.36	2.80	4.26	6.10	18.60	65.60

Table D2 Fatty acids in *Cissus populnea*

S/NO	CHEMICAL FORMULA	COMPOUND NAME	% COMPOSITION
1	C_{17} H_{34} O_2	Pentadecanoic acid	2.14
2	C_{16} H_{32} O_2	n-Hexadecanoic acid	12.16
3	C_{25} H_{48} O_2	15-Tetracosenoic acid	2.00
4	C_{18} H_{34} O_2	Oleic acid	8.75
5	C_{30} H_{50} O	Friedelan-3-one	61.76
6	C_{20} H_{35} F_5 O_2	Pentaflouropropionic acid	13.18

APPENDIX E

Table E1: Summary of baked tensile and compressive strength developed by various binders

S/No	Researcher	Year	Binder used	Baked tensile strength developed (KN/m^2)
1	Ademoh and Abdullahi	2008	Gum Arabic class iv 13%	932
2	Olakanmi and Arome	2009	3% each of melon seed oil and beniseed oil blended	3224(baked compressive strength)
3	Ademoh	2010	3% each of gum Arabic and neem oil blended	680
4	Achiv, Aponbiede and Hassan	2010	*Cissus populnea* 5%	932
5	Aponbiede	2000	Cassava starch 3%	550
6	Aponbiede	2004	Soya bean oil 3%	656
7	Aponbiede	2000	Cotton seed oil 3%	467
8	Aponbiede	2000	Groundnut oil 3%	362
9	Aponbiede	2004	Rubber seed oil 3%	1984
10	Aponbiede	2004	Cassava starch 2%, rubber seed oil 3% blended	2622
11	**Achiv**	**2011**	***Cissus populnea* 7%**	**1380 3225.7 (baked compressive strength)**