MODIFICATION OF GUM ARABIC

by

S O W U N M I , S a m u e l

A thesis submitted to the Postgraduate School, Ahmadu Be11o University, Zaria, in partial fulfilment of the requirement of the degree of M.Sc Chemical Engineering.

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CERTIFICATION

This thesis entitled MODIFICATION OF GUM ARABIC by SOWUNMI Samuel meets the regulations governing the award of the degree of Master of Science (Chemical Engineering) of Ahmadu Bello University, and is approved for its contribution to knowlledge and literary presentation.

..... Date.....

Chairman, Supervisory Committee

..... Date 9th Jan 1991

Member, Supervisory Committee

..... Date 11th Jan 1991

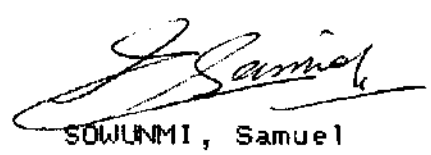
Head of Chemical Engineering

..... Date 30-5-91

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DECLARATION

I hereby declare that this thesis has been composed by myself and it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of informations are specifically acknowledged by means of references.



SOWUNMI, Samuel

14th June, 1990

D E D I C A T I O N

This work is dedicated to my late father Pa S.D. Sowunmi, my mother, sister, brothers, nephew nieces and Miss F.M. Jacobs.

ACKNOWLEDGEMENT

I remain grateful to Dr. R.O. Ebewele my initial supervisor and Dr. O. Peters my present supervisor for their constructive criticisms during the course of this work. Also worthy of mentioning is Dr. S.S. Adefila my Head of Department for his advice, Mr. Nelson and Mallam Musa of polymer testing laboratory, Chemistry Department, A.B.U., Zaria for their help in the stress-strain test. I lastly thank God for his love and kindness.

A B S T R A C T

The physical and chemical modifications of gum arabic have been attempted. The physical method involved the p1asticization of gum arabic with sorbitol, glycerol and ethylene glycol . The chemical method was by acid hydrolysis, acetolysis and acetate formation. The films Cast from the modified and untreated gumarabic so1utions were subjected to stress-strain analyses and bond strength tests.

It was found that the modulus of rigidity and ultimate tensile stress for the chemically modified gum arabic samp1es were generally higher than for the physical1y modified samples.

However, the physically modified samples had the higher-strain at break values. In all, the strain at break values of modified samples were found to be higher than for the untreated gum arabic sample, implying tougher films for treated gum arabic samp1es than for untreated ones.

Of the physically modified samples, the sorbitol plasticized gum arabic (with 3%. sorbitol) was found to have the best adhesive properties, while for the chemically modified samples, the 6%. acetolysed sample was found to have the best adhesive properties.

Bond strength was found to decrease with increasing quantity of additive. The results observed are believed to be due to the extent of chain fragmentation or debranching for chemically modified gum arabic, and the bulkiness and polarity of p1asticizers used for the physically modified gum arabic.

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CHAPTER ONE

INTRODUCTION.

When some plants are wounded mechanically or by insect which could be bacterial or fungal, there is often exuded a viscous sticky fluid which tends to seal off the wound. This fluid is a plant gum and is often made of highly branched polysaccharides. Such an exudate from an acacia tree specie, which is mostly found in tropical areas, is known as gum arabic. This gum is unique in that it is only produced by trees when they unhealthy. Gum arabic vary in type with varying sources. Several acacia species are botanically known, some of which are Acacia senegal, A. mollisima, A. pycnantha, A. cyanophylla, A. seyal etc.. Countries where appreciable quantities of gum arabic are produced include Sudan and Nigeria. Other countries such as Senegal, Mali, Mauritania, Tanzania, Morroco, Ethiopia and Somalia also produced sizable quantities of gum arabic, though inferior to those obtained from Sudan (1). An undocumented survey revealed that a large percentage of gum arabic produced in Nigeria are from Borno, Gongola, Kaduna, Katsina and Sokoto states.

As a result of its numerous applications such as binders, emulsion stabilizers, fabric stiffeners, adhesives etc., gum arabic has acheived commercial importance. Tables 1.1 and 1.2 show imports of gum arabic from Sudan and Nigeria

to France and the United Kingdom for the period 1979 to 1985

Table 1.1

Gum arabic: imports to France, 1979-1985

Year	Total imports (tonnes)	Sudan imports (tonnes)	Sudan price (#'000)	Nigeria imports (tonnes)	Nigeria price (#'000)	Others imports (tonnes)
1979	13622	10454	5984	47	25	3121
1980	11939	9009	5296	151	42	2779
1981	12051	9333	6627	252	134	2466
1982	12382	8901	7674	696	487	2785
1983	15064	13299	13441	255	202	1510
1984	10564	9682	10763	150	106	732
1985	9559	7870	8775	256	312	1433

Source: Overseas Development Natural Resources Institute (ODNRI), United Kingdom, Bulletin No.2, 1988

Table 1.2

Gum arabic: imports to the United KIngdom, 1979-1985

Year	Total imports (tonnes)	Sudan imports (tonnes)	Sudan price (#'000)	Nigeria imports (tonnes)	Nigeria price (#'000)	Others imports (tonnes)
1979	5162	2007	1270	896	645	2259
1980	3917	989	604	758	456	2170
1981	4889	1956	1416	583	369	2350
1982	4532	1684	1409	963	635	1885
1983	10089	7276	6808	403	290	2410
1984	8851	6329	6626	228	201	2294
1985	6653	3642	6405	750	1043	2261

Source: ODNRI U.K., Bulletin No.2, 1988

The traditional area of use of gum arabic is in the area of adhesive where it is being used for stamps, stationaries, packaging and binding adhesives. However, gum arabic is now facing stiff competitions from some other gums. It has virtually given way to synthetic gums in the area of adhesive (11). Similarly, a recent undocumented survey has shown that at the Nigerian Tobacco Company, Zaria, gum arabic has completely given way, in its use as a packaging adhesive, to other gums. The setbacks being experienced by gum arabic may be due to the brittle nature of the gum when dehydrated.

Gum arabic is a highly branched polsaccharide with a variable molecular weight which is an indication of its heterogeneity. Its molecules are in the shape of short stiff spirals with numerous side chains and a coil length of 1050 A at maximum molecular charge (1). Some propositions, based on the products of mild hydrolysis of the gum, have been put forward regarding the structure of gum arabic. The gum has a main structural feature backbone chain of (1-3) linked D-galactopyranose units, some of which are substituted at C-6 with various side chains (1).

The main cause of its brittleness can be attributed to its branched and polydispersed nature. This is because amylose, an unbranched fraction of starch, is known to form a more flexible film than amylopectin which is a highly branched fraction of starch (3) due, largely, to orderly arrangement of the former. Polystyrene, with a bulky side group, is also known to be more brittle than polyethylene due to polyethylene's orderliness. It could therefore be said that bulky side groups or side chains in the arabic gum are responsible for its brittleness by inducing chain stiffness due to steric effect and reducing Van der Waals force. The branched nature of this gum, coupled with its properties of imbibing large quantities of water, resulting in dispersion of high viscosity, might also be responsible for the adhesion of the gum to hydrophilic surfaces.

In this work, the aim is to reduce the brittleness of gum arabic with as little in its adhesive and other physical properties as possible. In synthetic polymers, brittleness is normally overcome by incorporating plasticizers into such polmers. Plasticizer molecules normally enter between polymer molecules with the resultant effect of enhancing chain mobility. Another method that may be used, with particular reference to gum arabic, is to debranch or fragment the gum. This involves chemical modification of the gum to derivatives that may not be as brittle as the gum. This chemical and physical modification of gum arabic will be attempted in this work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Polysaccharides

Polysaccharides have been described as high molecular weight polymers formed by condensation of many monosaccharide units or their derivatives. (2). they have also been described as polymeric substances, the building blocks of which are monosaccharides. (3). From the foregoing, polysaccharides could be said to be long chain carbohydrate molecules built from some monosaccharides such as glucose, galactose, rhamnose etc. or their derivatives. Polysdaccharides could be classified based on their chemical compositions. In this regard, a polysaccharide which yields only one type of monosaccharide on hydrolysis is called a homoglycan e.g. starch, while those which yield two or more types of monosaccharides are called heteroglycans e.g. gum arabic. Polysaccharides could also be classified , based on linearity, as linear (polsaccharides without side chain e.g. amylose) and branched (polysaccharides with side chains e.g. gum arabic).

2.2 Structure

Polysaccharides are normally isolated from their natural enviroments (without much degradation), for study. When monosaccharides come together to form polysaccharides, an

anomeric hydroxyl group of one monose unit can condense with any hydroxyl group other than that of the former. The few monoses which occur as components of polysaccharides are D-glucose, D-fructose, D-galactose, D-xylose, L-arabinose, D-glucosamine, D-galactosamine and D-glucuronic acid. These monoses are shown in Figure 2.1

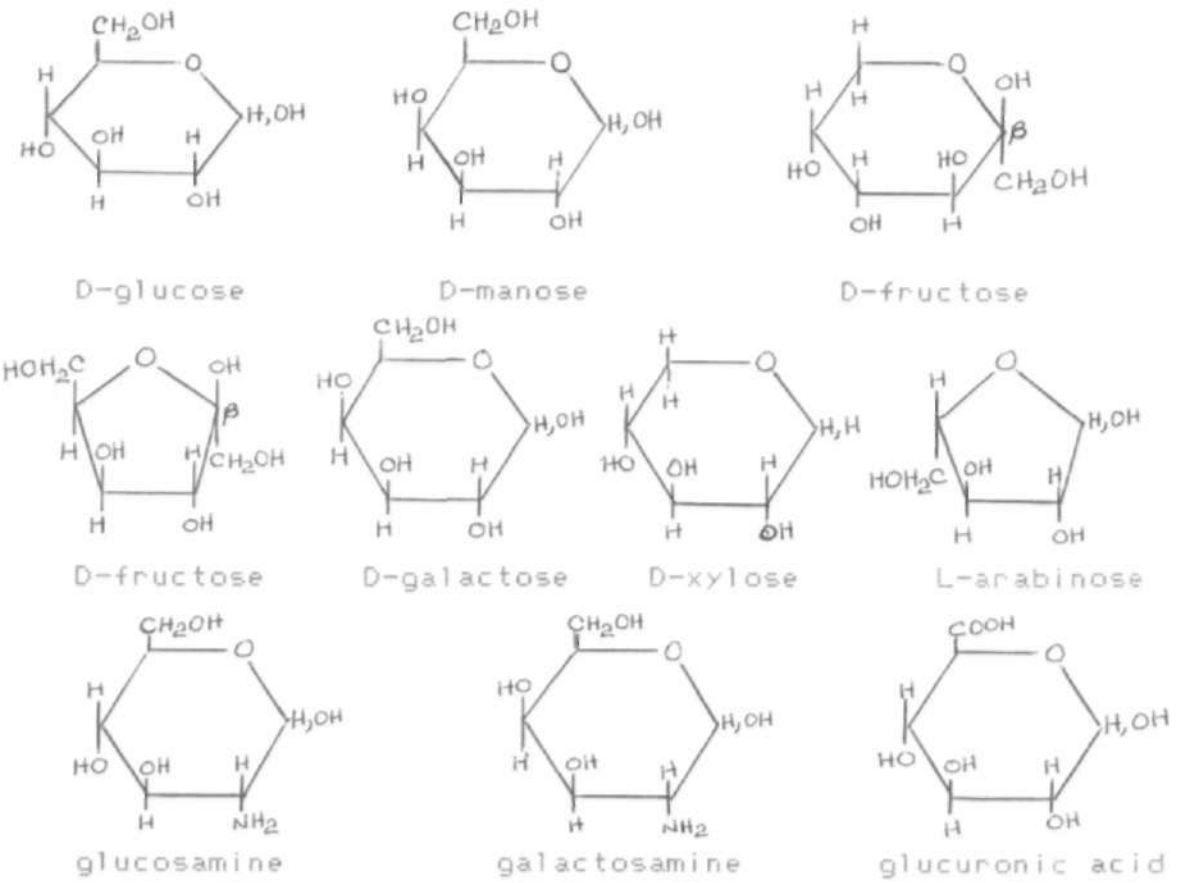


Fig. 2.1: Some monomers which are found as components of polysaccharides

Homoglycans are the most abundant of polysaccharides (1) with either a linear or branched structure as shown in Figure 2.2. The branched structure could be multiplly branched or even branch on branch.

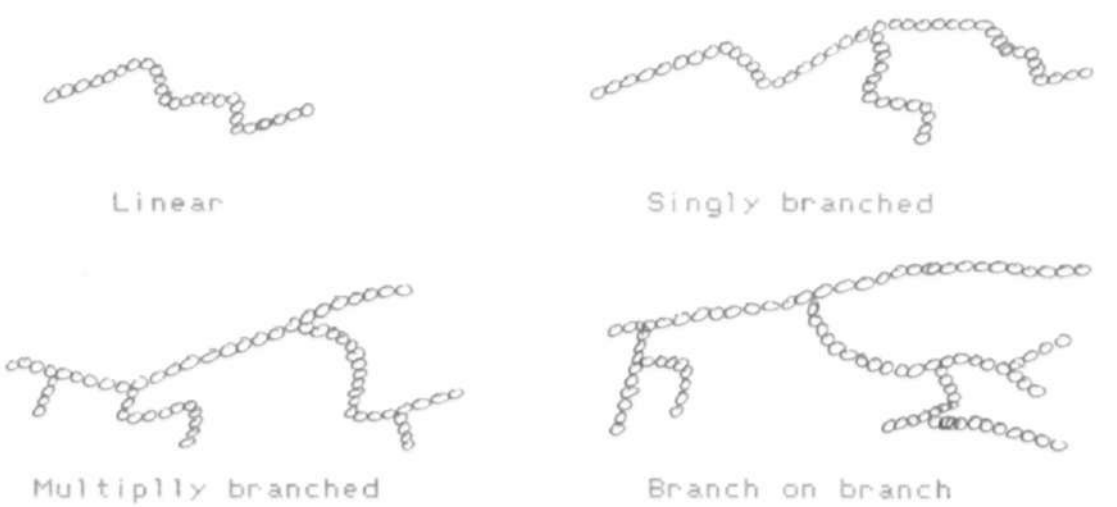


Fig. 2.2: Some homoglycan structures

Some common polysaccharides include cellulose, starch (amylose and amylopectin), glycogens, fructans, hemicellulose, plant gum (e.g. gum arabic) and some animal polysaccharides like dextran and chitin.

2.3 Structure and composition of Gum arabic

Hydrolysis of gum arabic yields L-arabinose, L-rhamnose, D-galactose and glucuronic acid (1). Autohydrolysis of arabic acid also gave 34.4% L-arabinose, and 14.2% L-rhamnose, plus 3-O-β-D-galactopyranosyl-L-arabinose and degraded gum arabic which on further hydrolysis with mineral acid produces 42.1% of D-galactose, 15.5%

glucuronic acid and some 6-O-(β -D-glucupyranosyluronic acid)β-D-galactose. (1).

Mild hydrolysis of gum arabic has been reported to yield L-arabinose, L-rhamnose, 3- β -D-galactopyranosyl -L-arabinose, shown in Figure 2.3 and a degraded arabic which on further hydrolysis yields additional

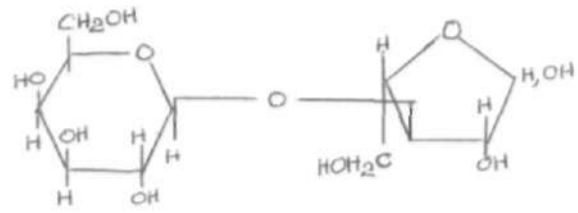


Fig. 2.3: 3-β-D-galctopyranosyl-L-arabinose

sugars D-galactose, D-glucuronic acid and 6-β -D-glucupyranosyl-D-galactose shown in Figure 2.4 (1).

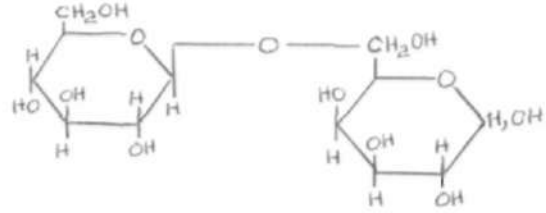


Fig. 2.4: 6-β-D-glucupyranosyl-D-galactose

Some gum arabic structures have been proposed (1,2), based on the result of mild hydrolysis of gum arabic. These proposed structures are shown in Figures 2.5, 2.6 and 2.7.

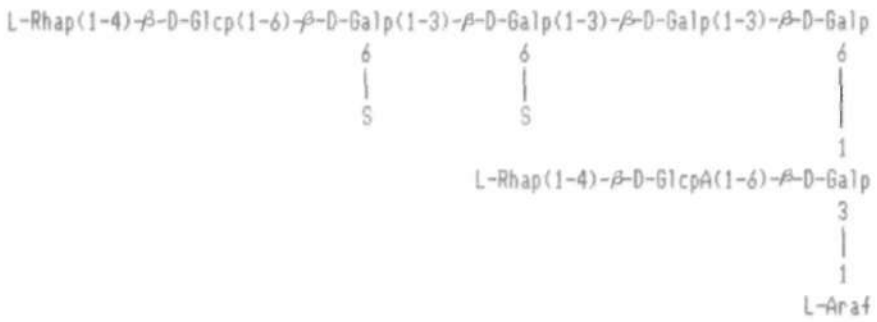


Fig.2.5: One of the proposed gum arabic structures (1)

where S is a side chain of

3-D-Galp(1-3)-L-Araf(1-3)-L-Araf(1-, or

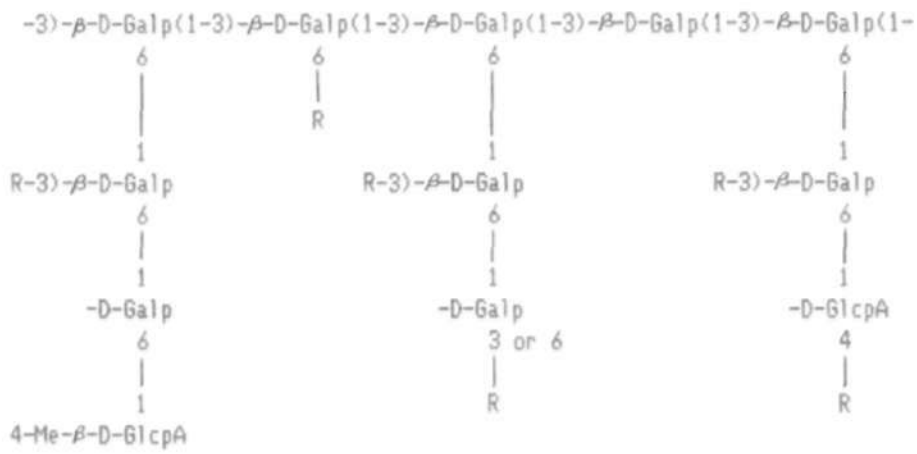


Fig. 2.6: Proposed structure for acacia mearnsii gum

where R is L-Araf(1-, L-Araf91-3)-L-Araf(1-, L-Rhap(1-
L-Araf(1-5)-L-Araf(1-, or -L-Arap(1-3)-L-Araf(1-.

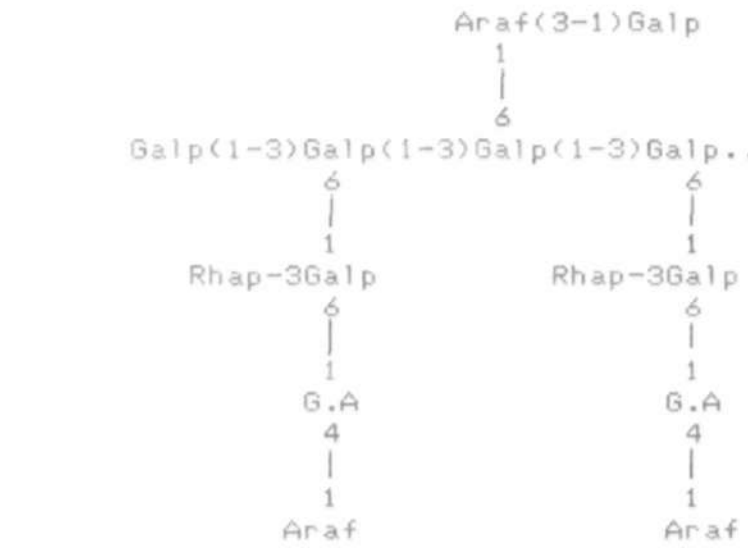


Fig. 2.7: Proposed um arabic structure (2).

where G.A is glucuronic acid.

These proposals are all in agreement with a (1-3) linked galactopyranose backbone sructure with high degree of branching, mostly at the C-6 position. The regularity of the branches is however not known. This branched nature of

gum arabic and the ability to imbibe a lot of water to form a high viscosity dispersion, are responsible for the adhesion of gum arabic to hydrophillic surface and compartibility of gum arabic with structurally and chemically identical compounds.

2.4 Polsaccharides Structural Modification

2.4.1 Starch acetate

Stach acetates derivative has been reportedly prepared by the action of starch wth acetic anhydride or vinyl acetate (4). The products so formed are low substituted starch esters with good hydrating capacity, flow, filming and viscosity stability. They also give flexible films. The process by which this reaction occurs is still not clear, it is however possible that the branches are being substituted by the acetate group. This would lead to smaller side chains which might enhance chain flexibilty.

2.4.2 Hydroxylehtyl ethers

Hydroxylethyl starch ethers are products of reaction between ethylene oxide and starch (4). These ethers have properties similar to starch acetates including flexible film formation. The close resemblance of starch and gum arabicmkes acatate and ether derivatives formation likely to reduce the brittleness of gum arabic.

2.4.3 Acid hydrolysis

Acid hydrolysis of polysaccharides normally breaks polysaccharides down to their monomers, dimers and some oligosaccharides (2,3,5). The products of this hydrolysis are low viscous liquid. The acid hydrolysis is believed to fragment the molecules by cleaving bonds other than the (1-6) which is the most resistant to acid hydrolysis (3,5).

Acid catalysed hydrolysis of O-glycosides yields corresponding alcohols and some reducing sugars via some protonated intermediates (5). This hydrolysis of monosaccharides is slow reaction with rate constant values in the range 10^{-4} S^{-1} to 10^{-6} S^{-1} at acid concentrations within the range 0.01M to 0.5M HCl or H_2SO_4 (5). The rate constant was also shown to increase with increasing acid concentration. It is therefore believed that at very high concentration, the reaction will be very fast.

Acid hydrolysis sometimes lead to reversion, a situation where by tthe monosaccharides and oligosaccharides formed, combine together in the acidic medium to form higher oligosdaccharides (2,3,5).

2.4.4 Acetolysis

Acetolysis has been described as the treatment of polysaccharides with a mixture of acetic acid and acetic anhydride (in equal weights), in the presence of concentrated sulphuric acid. Products of this reaction have

their (1-6) link cleaved contrary to acid hydrolysis in which the (1-6) is very resistant (3,5,6,7). This (1-6) link is the least resitant to acetolysis (3,5). It is therefore believed that for a polysaccharide which has the (1-6) link as its branching points, the product of such acetolysed polysaccharide will be almost linear polysaccharide.

2.5 Plasticization

Plasticization involves the incorporation of plasticizer molecules into a polymer. Plasticizer molecules enter between molecules and seperate the polymer molecules. Polar plasticizers, compartible with polsaccharides, are attracted to polysaccharide molecules by their polar group (8). These attraction causes a replacement of polymer-polymer bonds with polymer-plasticizer bonds. The bulkiness, configuration and polarity of such plasticizers are such that arrangement of polymer molecules is affected to give room for side chaind and bulky side groups and allow easy slippage of polymer molecules past one another.

In plasticization, polymer-plasticizer compartibility is very impotant. A U.S. Dispensatory report (1) indicates that the following compounds are not compartible with gum arabic: aminopyrine, pyragallol, morphine, guaiacol, cresols, eugenol, acetyl eugenol, apormorphine, eserine, epinephrine, isobarbaloin, caffeotanic acid, gallic acid and tanin. The following compounds are however compartible

with gum arabic: ethylene glycol, diethylene glycol, sorbitol, glycerol and some other aiditols. Methyl celluloses are also included. All the compounds said to be compartible with gum arabic are high boiling liquid miscible with water, which makes them humectant. Apart from replcement of polymer-polymer bond with polymer-plasticizer bond, they also help retard rate of evaporation of water from the gum solution. It is believed that the ones with the higher boiling point will be more effective as they would readily retain water in the gum solution. Corn syrup, glycerin, urea, sorbitol and inverted sugars have been used as humectants in starch plasticization.

CHAPTER THREE

EXPERIMENTAL

3.1 Beneficiation

Gum arabic was obtained from Zaria main market as small chips with dirts and tree barks. These were purchased and beneficiated in batches.

The cleaning and stock preparation of the gum was done by dissolving a known weight of the crude gum in a known weight of water for two days. Thereafter, the resulting gum arabic solution was seived through a 0.125mm seive.The filtered material, which was mainly dirts, was bone-dried and weighed while the filtrate was centrifuged using a General laboratory centrifuge (GLC2 type, Dupont Instrument) at 2500 revolutions per minute for thirty minutes. The clear gum arabic solution was decanted, weighed and stored in 2.5 litre storage bottles marked "STOCK". The gum arabic solution is hereafter referred to as THE STOCK. The impurities, that is the centrifuge residue and filter cake recovered above, were combined, dried and weighed.

The gum arabic concentration in the stock was determined through a caliberation curve shown in Figure 3.1. The was constructed using known weights of gum arabic in 500g of the stock as discussed in Appendix 3.

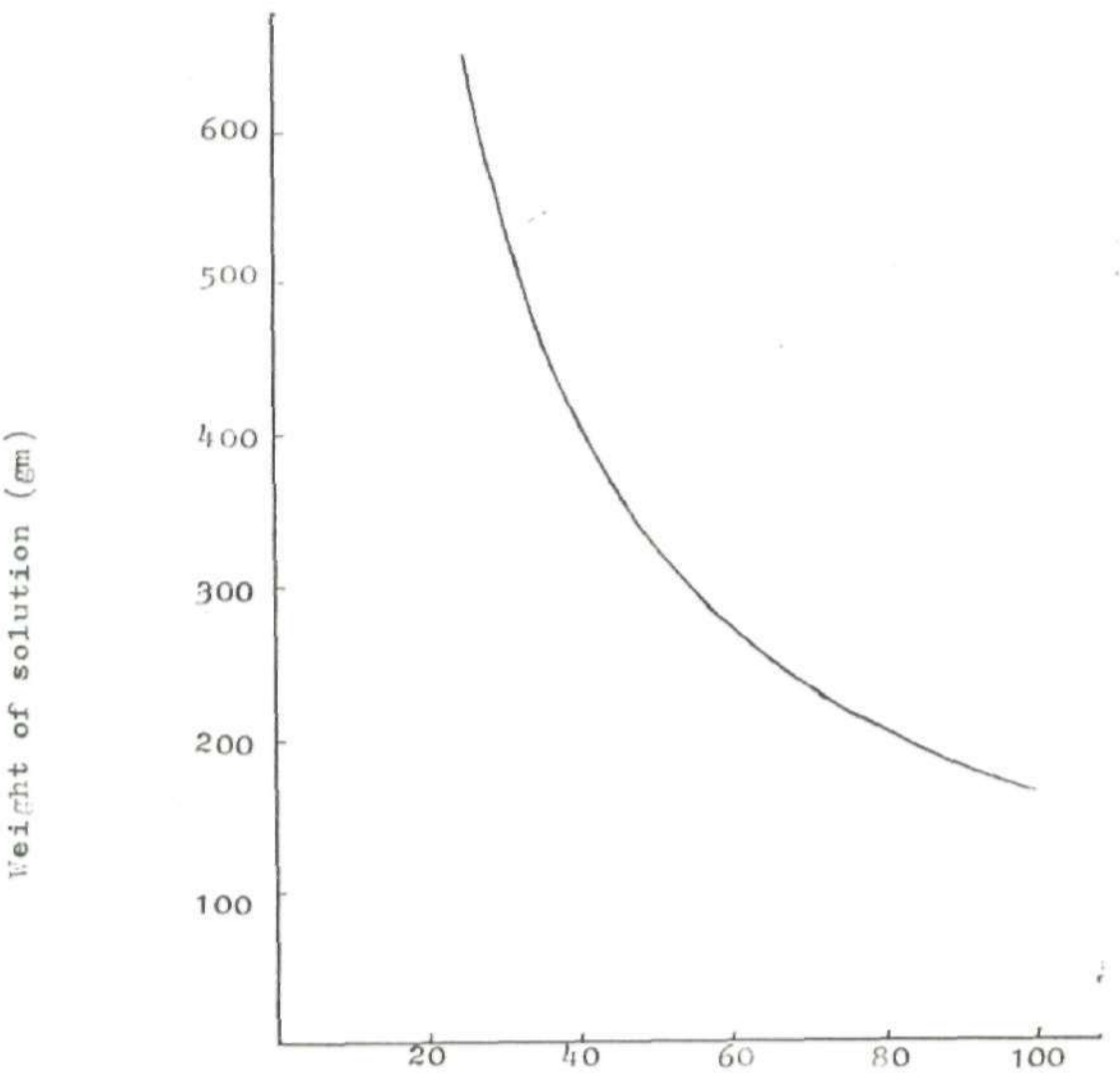


Fig. 3.1: Caliberation curve for the determination of the concentration of gum arabic

3.2 Chemical Modification

Chemical modification of gum arabic was by acid hydrolysis, acetolysis and acetate formation.

3.2.1 Acid hydrolysis

500g of the stock was weighed into a beaker and heated to ± 2°C. 16.29g of concentrated sulphuric acid (corresponding to 10 weight percent of dry gum arabic in the stock) was then added to the weighed stock and was held at about 70°C for four hours with continous stirring using a regulator hot plate magnetic stirrer.

After the hydrolysis, the mixture was left to cool to room temperature after which its viscosity was measured with a Brookfield synchro-electric viscometer (RVT model).

The procedure was repeated with the following quantities of sulphuric acid: 11.4g, 8.15g and 4.29g corresponding to 7, 5 and 3 weight percent of dry gum arabic respectively.

3.2.2 Acetolysis

Acetolysis was carried out using an acetolysing mixture prepared as follows: 1:1 (weight/weight) ratio of acetic acid and acetic anhydride were thoroughly mixed in a round bottom flask. Thereafter, sulphuric acid (concentrated), corresponding to 3 weight percent of the mixture was added to the mixture. The mixture as prepared, is hereafter referred to as acetolyser.

500g of the stock was weighed into a beaker and heated to 70°C using a hot plate magnetic stirrer. 16.29g of the acetolyser (corresponding to 10 weight percent of dry gum arabic) was then added to the hot stock with the temperature being held at 70°C for four hours, after which the mixture was cooled to ambient temperature and its viscosity measured.

The reaction was repeated with the following quantities of acetolyser: 11.4g, 8.15g and 4.29g.

3.2.3 Acetate formation

Gum arabic acetate derivative was prepared using aceitc anhydride as outlined below.

500g of the stock was weighed into a beaker. The stock was heated to 70°C and 16.29g of acetic anhydride was added. The mixture was held at 70°C for four hours, after which it was left to cool to room temperature and its viscosity was measured.

This procedure was repeated with the following quantities of acetic anhydride: 11.4g, 8.15g and 4.29g.

3.3 Physical Modification of Gum Arabic

The physical modification of gum arabic involved plasticizing the gum arabic with three different compounds viz: sorbitol, glycerol and ethylene glycol.

3.3.1 Sorbitol

An aqueous solution of sorbitol was prepared to allow for easy mixing with the stock,as follows: 65g of sorbitol powder was weighed into 51g of distilled water. The resulting colloidal mixture was heated at about 95°C to a clear solutioin containing 56 weight percent sorbitol.

500g of the stock was weighed into a beaker and concentrated to about 70 weight percent at 70°C. 29.01g of the prepared sorbitol solution (corresponding to 16.29g of sorbitol powder and to 10 weight percent of dry gum arabic) was added to the concentrated stock. The mixture was thoroughly stirred and left to cool to room temperature. The viscosity of the resulting mixture was measured.

The procedure was repeated with the following quantities of sorbitol : 20.36g, 14.55g and 7.66g corresponding to 11.4g, 8.15g and 4.29g of sorbitol powder respectively.

3.3.2 Glycerol

500g of the stock was concentrated in a beaker at 70°C , to about 70 weight percent. 16.29g of glycerol was then thoroughly mixed with the concentrated stock and allowed to room temperature after which its viscosity was measured.

The procedure was repeated with the following quantities of glycerol: 11.4g, 8.15g and 4.29g.

3.3.3 Ethylene glycol

Ethylene glycol (BDH) wwas used as received. A similar procedure to that of glycerol, was employed for the plasticization of gum arabic with ethylene glycol. The following quantities of ethylene glycol were used: 16.29g, 11.4g, 8.15g and 4.29g.

3.4 Physical Measurements

Physical tests involving stress-strain and bond strength were carried out using an Instron tensile testing machine (Instron table model 1026, Machine Company, England).

The results from these tests were obtained using the following stress-strain relationship. The tensile stress is given as

$$\sigma = L*g/A$$

and the strain

$$\varepsilon = \Delta I/I$$

where

σ = tensile stress (N/m^2)

ε = strain

L = tensile load (Kg)

A = cross-sectional area of test piece (m^2)

I = guage length of test piece (m)

ΔI = extension of test piece (m)

g = acceleration due to gravity (m/s^2)

The bond strength σ b is given as

$$\sigma b = Lb * g/Aa$$

where Lb = adhesive breaking load (Kg)

Aa = contact area of adhering surfaces (m^2)

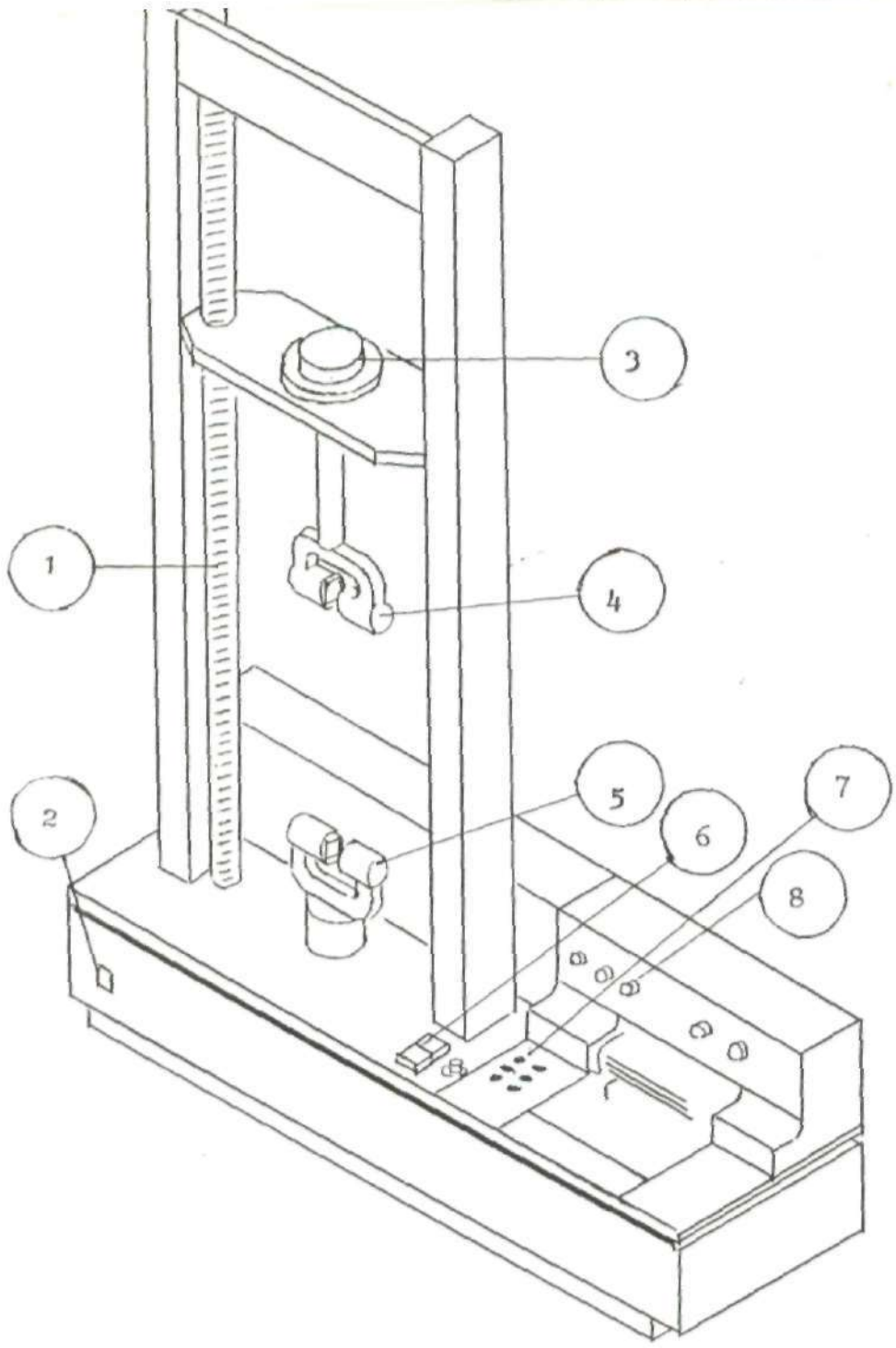
3.4.1 Stress-strain test

For each of the products of various treatments carried out in this work, films were cast and test pieces, as shown in Figure 3.3, were cut. The thickness of the test pieces were measured using a micrometer screw guage, before being subjected to a constant strain rate of 100mm per minute. The corresponding loads needed to produce different strains were recorded by the tensile testing machine. Each test piece was strained to failure.

The Instron tensile testing machine (Instron table model 1026), shown in Figure 3.2 was used for both the stress-strain and bond strength tests. The Instron is a versatile machine that automatically produces a load-extension curve as the tests are run.

The machine is equiped with a load cell (varying from 50g to 50kg) which measures the load experienced by it (by the inbalance of an incorporated wheatstone bridge). The load cell is electrically connected to an attached chart assembly.

The machine is normally left on for at least one hour before being used to reduce noise interference. The machine is first caliberated by placing a known weight



1. Drive screw
2. Mains switch
3. Load cell
4. Upper jaw
5. Lower jaw
6. Cross head controls
7. Recorder controls
8. Load cell amplifier controls

Fig. 3.2: Instron tensile testing machine

(usually 5kg) on the moving jaw attached to the load cell, and adjusting the pen of the chart to a fixed deflection as may be desired.

An appropriate strain rate and chart to cross head ratio is selected from the gear box assembly, after which specimen may be placed in the machine (clamped by the lower fixed jaw and upper moving jaw). The up ward movement of the cross head (load cell) and the chart movement are actuated at the same time. This ensures that load extension curve is produced as the specimen is strained.

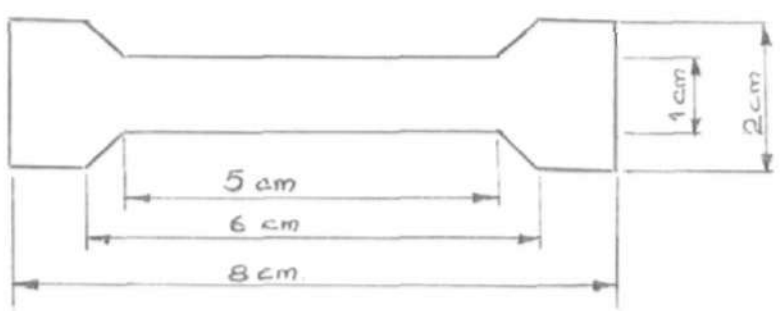


Fig. 3.3: Tensile test piece.

3.4.2 Bond strength test

The bond strength test was carried out by fracturing a lap jointed adherends. The adherends used in this work are wood sheets prepared by carefully cutting out wood strips of 10mm by 50mm, and rinsing them in distilled water, after which they were dried on a flat surface with some weights placed on them to

prevent creasing and uneven drying. The strips were transferred to an oven maintained at 65°C for eighteen hours. This is to ensure uniform pretest conditions.

Lap joints of the prepared adherends shown in Figure 3.4 were made with a contact area of about 100mm^2 under a pressure of 1935N/m^2 for thirty minutes. The joints, made with equi-viscous grades of gum arabic samples were cured at 65°C for sixteen hours.

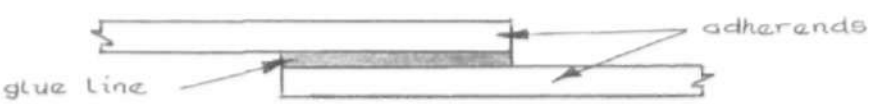


Fig. 3.4: A simple lap joint

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Stress Strain Analysis

4.1.1 Acid hydrolysis

The result of acid hydrolysis at 5, 7 and 10 percent sulphuric acid could not be presented because the resulting mixture had very low viscosities and could not be cast into films. This has been attributed to formation of low molecular weight oligomers arising from possible extensive hydrolysis. However, at 3 weight percent sulphuric acid addition, the sample showed some visible physical improvements. For instance, its viscosity went up from 100cp for 10 percent sulphuric acid to 28000cp, and also had good film forming tendency.

The stress-strain result (Figure 4.1) show that the modulus of rigidity, which is measure of hardness of a material, for the 3 percent hydrolysis was $0.21*10^{6}N/m^{2}$ compared to a value of $48.44*10^{6}N/m^{2}$ for untreated gum arabic. Similarly, the ultimate tensile stress, UTS, (the highest stress a material can withstand before yielding or fracturing) dropped from $12.97*10^{5}N/m^{2}$ for untreated gum arabic to $0.35*10^{5}N/m^{2}$

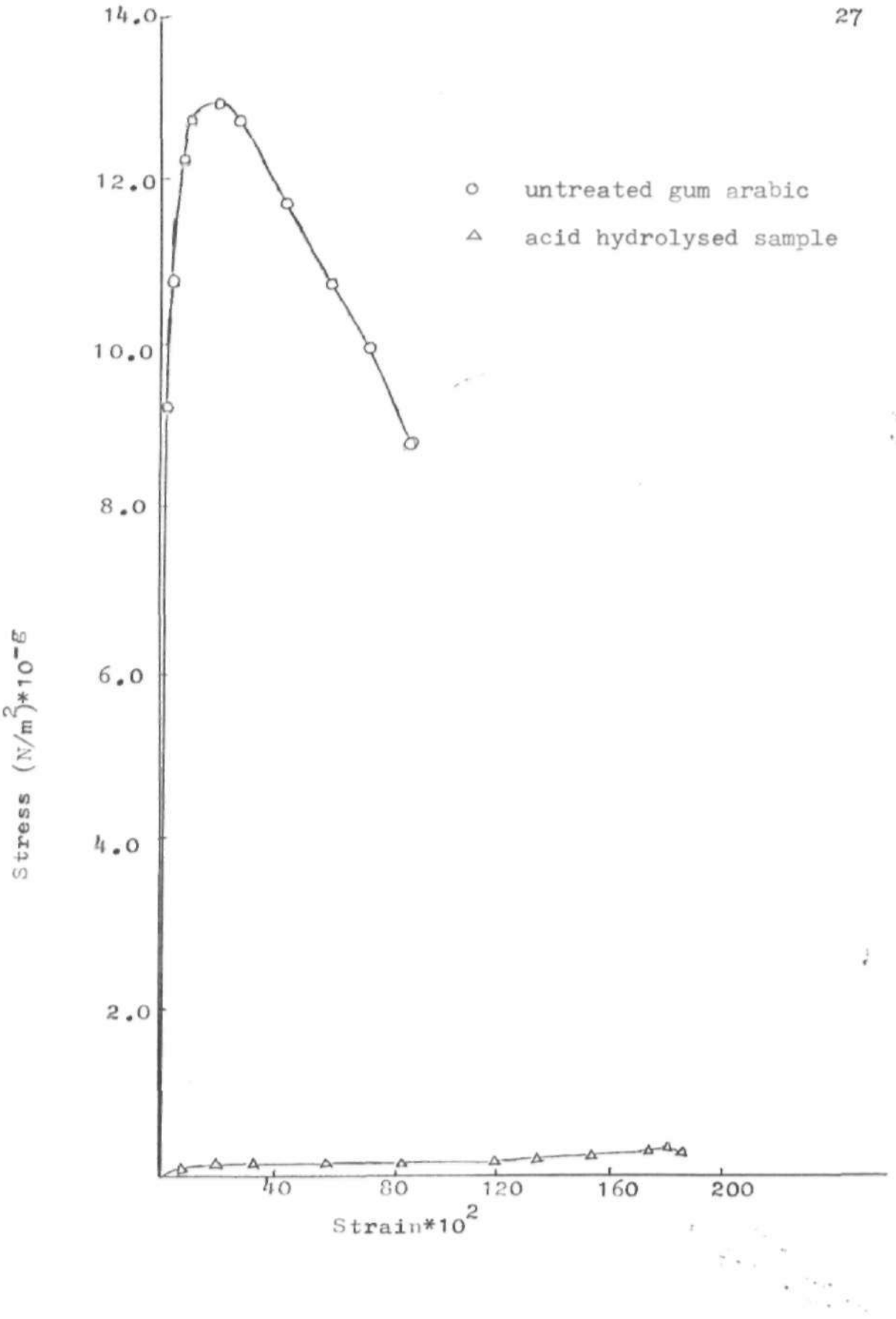


Fig. 4.1: Stress strain curves for H_2SO_4 hydrolysed and untreated gum arabic

for 3 percent hydrolysed gum arabic. The strain at break however appreciated from 0.87 for untreated gum arabic to 1.87 for 3 percent hydrolysed gum arabic.

Table 4.1: Some physical properties of hydrolysed and untreated gum arabic

	Viscosity (cp)	Modulus of rigidity (N/m^2) $*10^{-6}$	Ultimate tensile stress (N/m^2) $*10^{-6}$	Strain at break
Untreated gum arabic	43000	48.44	12.97	0.87
3% hydrolysed	28000	0.21	0.35	1.87
5% " **	20800	-	-	-
7% " **	13000	-	-	-
10% " **	100	-	-	-

** Samples that could not be cast into film.

It thus appears that hydrolysis of gum arabic under mild conditions of reactants reulted in a more flexible but tougher film than the untreated gum.

4.1.2 Acetolysis

Acetolysis of gum arabic was performed to possibly effect the (1-6) bond scission which occurs at the branch points. Except for the strain at break showed

an increase with increase in the concentration of the acetolyser, all other measured parameters showed inverse relationship with the concentration of the acetolyser. Thus, the modulus of rigidity of gum arabic dropped from $48.44*10^6 N/m^2$ for untreated gum arabic to $5.792*10^6 N/m^2$ for 10 percent acetolyser treatment as shown in Figure 4.2. Similarly, the ultimate tensile stress (UTS) showed a downward trend from $12.97*10^5 N/m^2$ for the untreated gum arabic to $2.7*10^5 N/m^2$ for the 10 percent acetolyser treatment. The variation of UTS with quantity of acetolyser used is shown in Figure 4.3, while the variation with strain at break is shown in Figure 4.4. These results suggest that generally, acetolysis resulted in a more flexible arabic gum

4.1.3 Acetic anhydride

The attempt to form acetate derivative of gum arabic with acetic anhydride produced films that appear more flexible and with comparable toughness than the untreated gum arabic. Thus the stress-strain results presented (in Figure APP2) show that the modulus of rigidity of the amples exhibited a downward trend with increasing quantity of acetic anhydride from $48.44*10^6 N/m^2$ for the untreated sample to

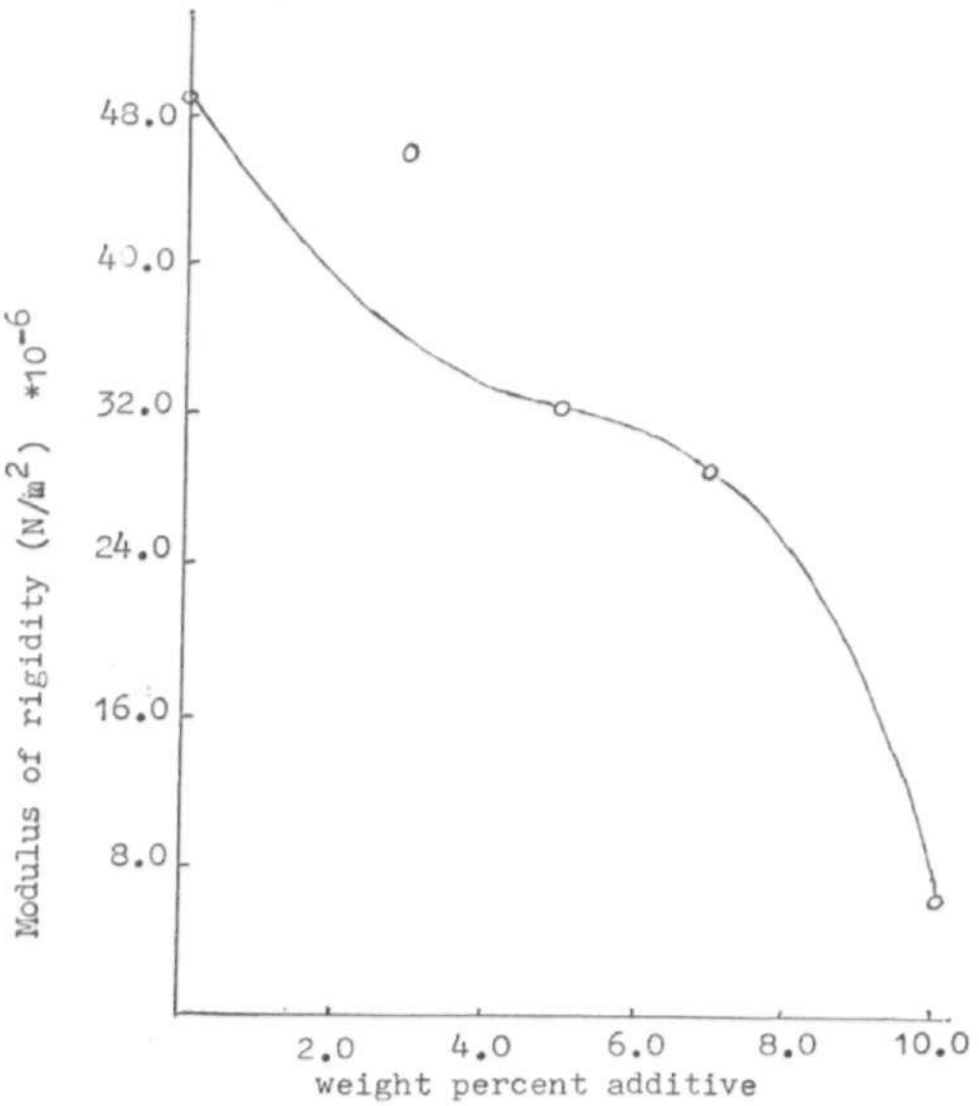


Fig 4.2: Variation of modulus of rigidity of acetolysed gum arabic with percent acetolyser used.

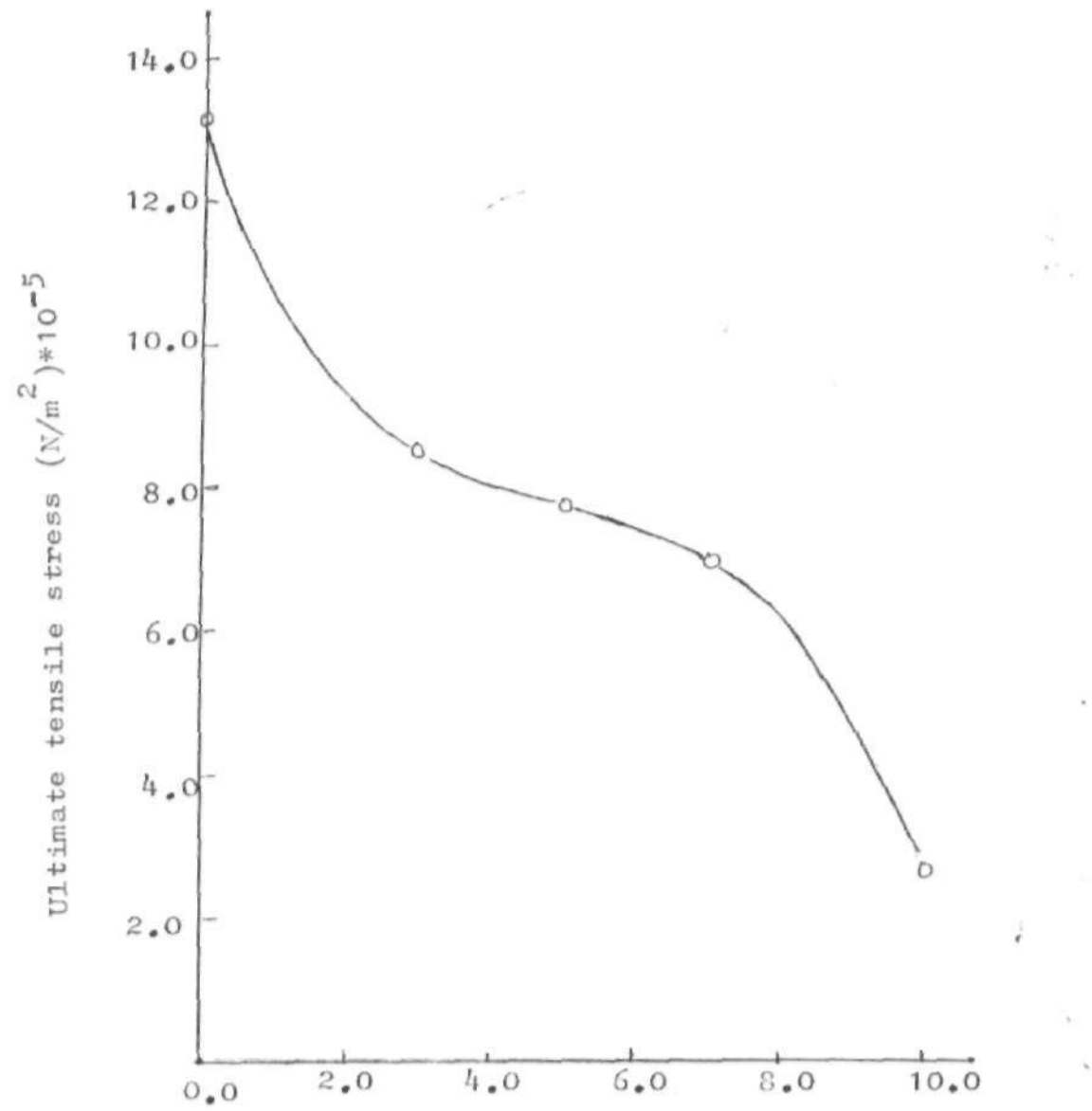


Fig. 4.3: Variation of ultimate tensile stress of acetolysed gum arabic with percent acetolyser reacted with gum arabic.

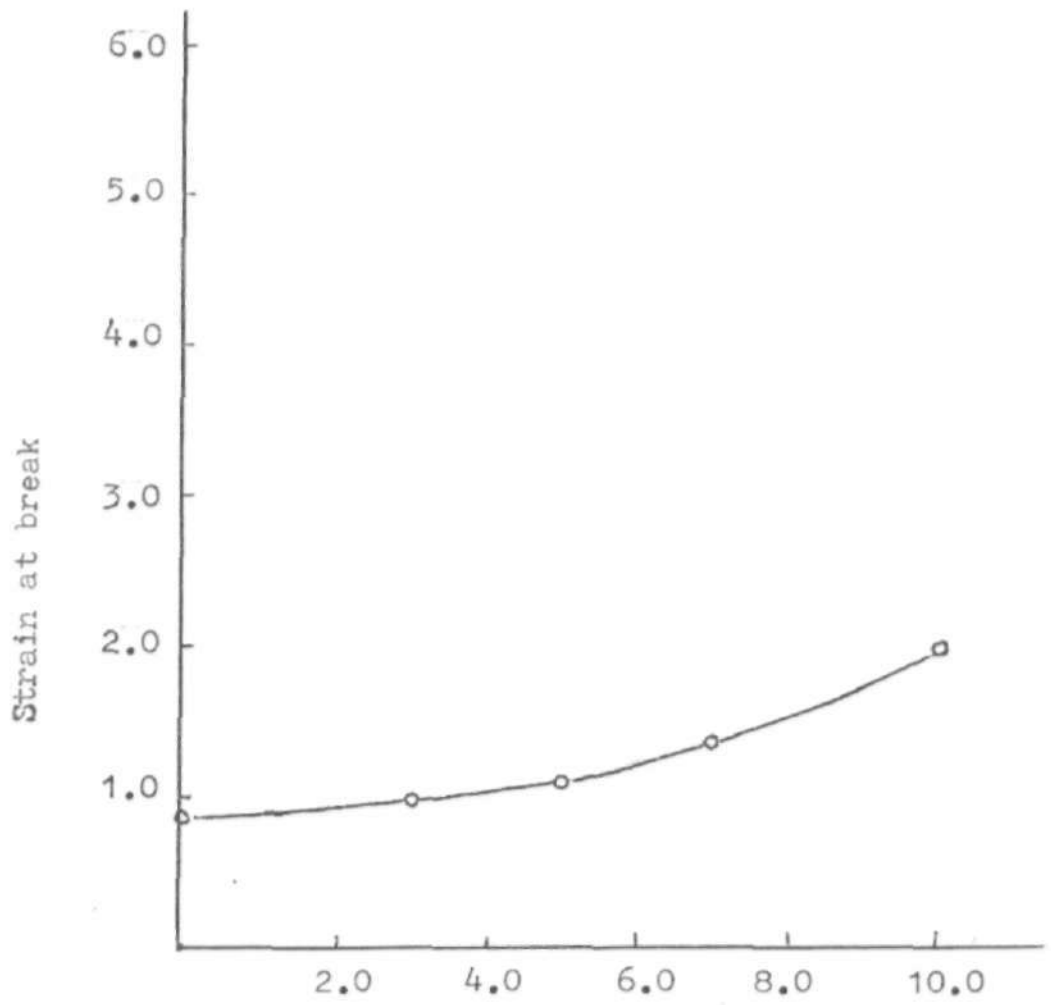
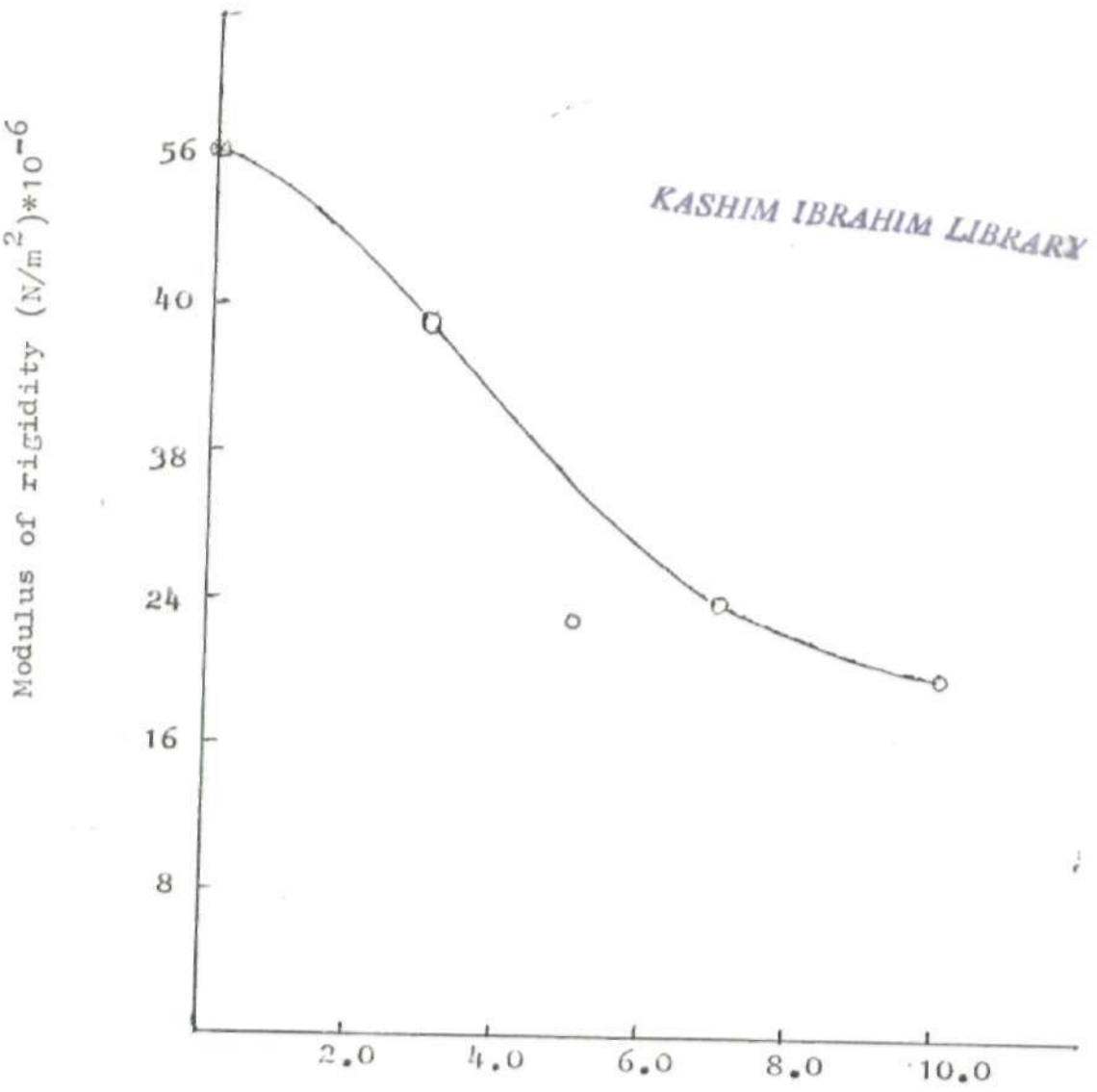


Fig. 4.4: Variation of strain at break of acetolysed gum arabic with percent acetolyser used.



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Fig. 4.5: Variation of modulus of rigidity with percent acetic anhydride reacted with gum arabic.

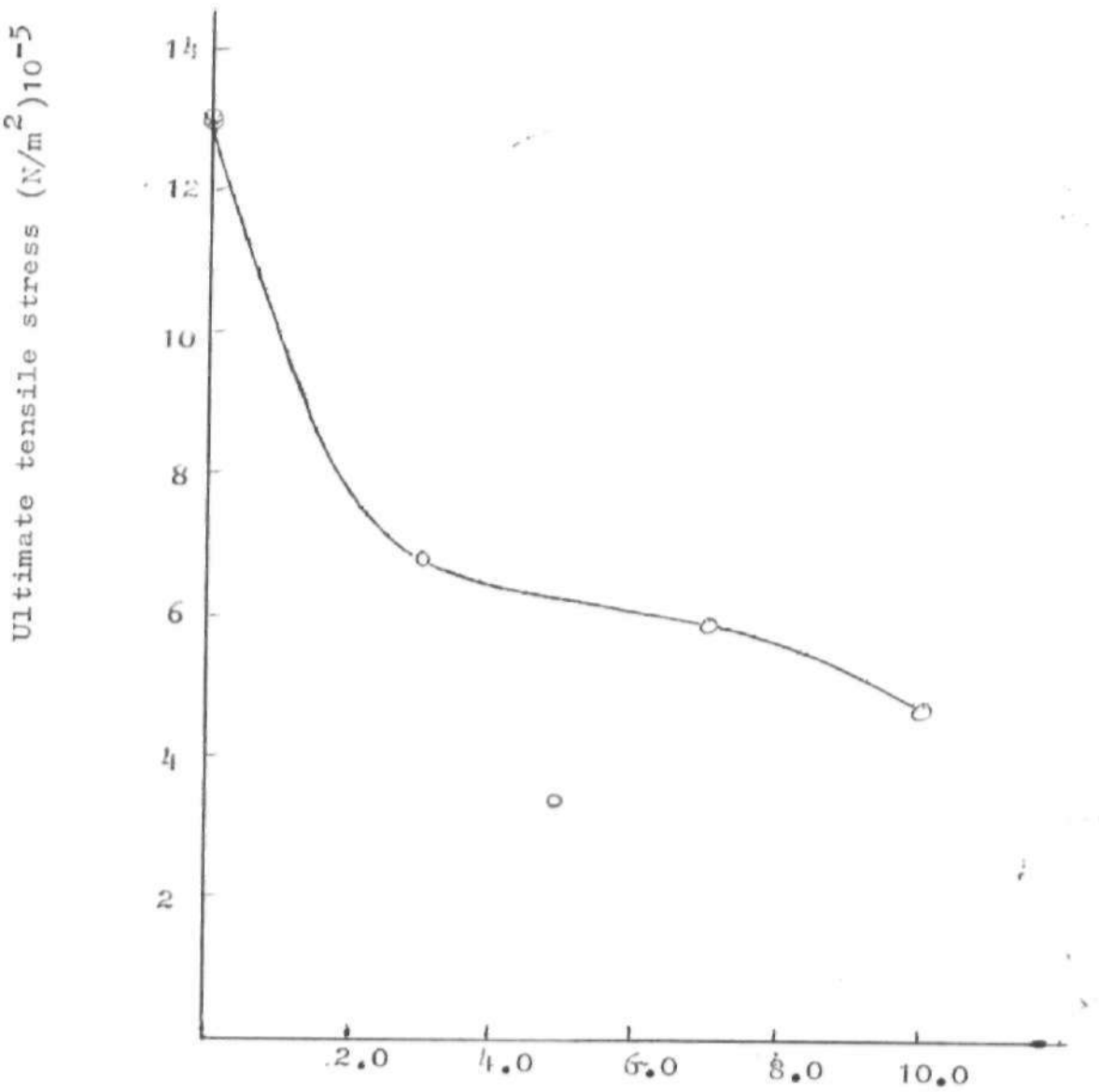


Fig. 4.6: Variation of ultimate tensile stress with percent acetic anhydride reacted with gum arabic.

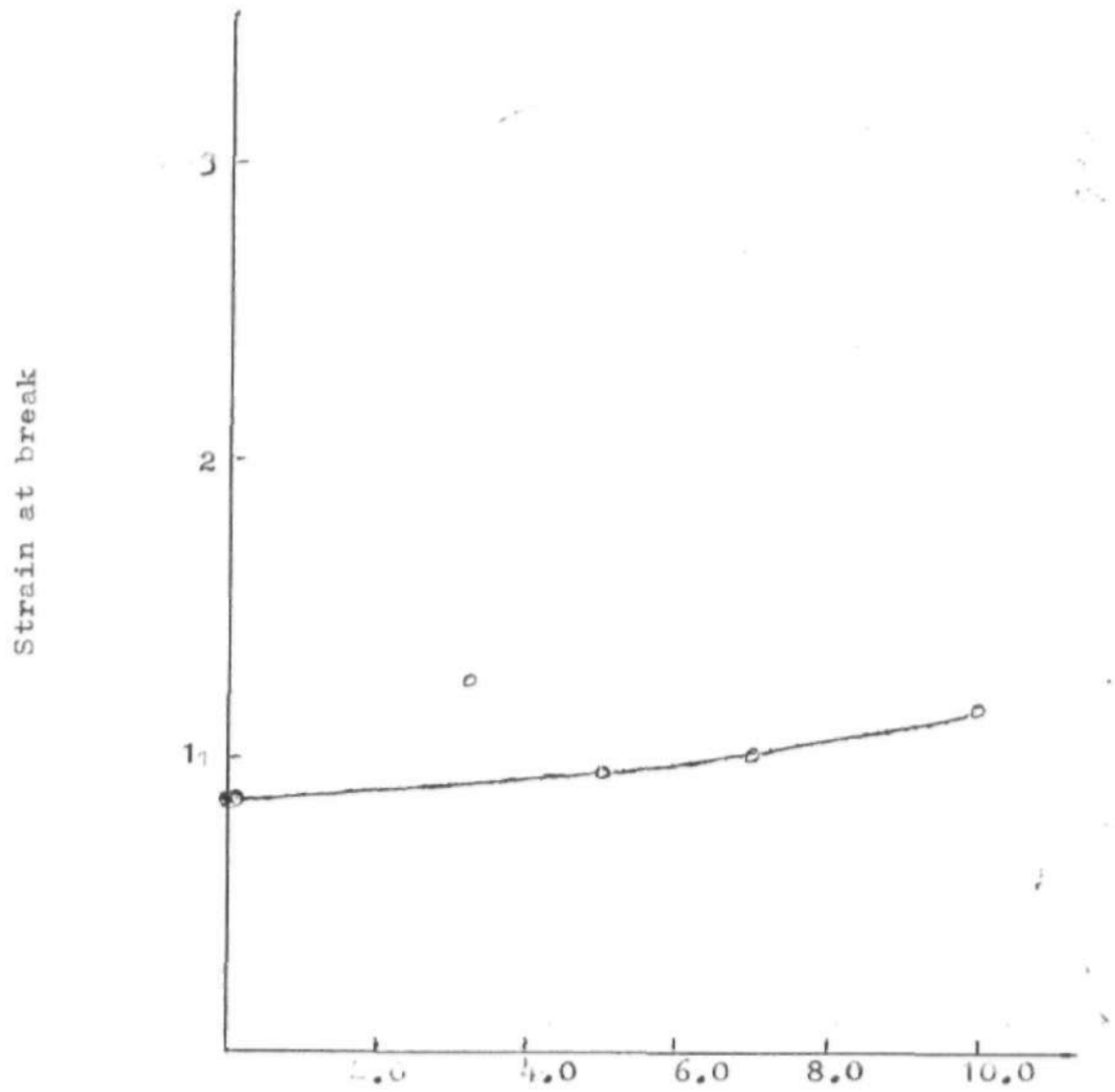


Fig. 4.7: Variation of strain at break with percent acetic anhydride reacted with gum arabic.

$20.313*10^6 N/m^2$ for 10 percent acetic anhydride addition as shown in Figure 4.5. Similarly, the UTS dropped from $12.97*10^5 N/m^2$ for the untreated sample to $4.73*10^5 N/m^2$ for the 10 percent acetic anhydride addition as shown in Figure 4.6. The strain atbreak values for these samples however, did not show any appreciable increase, despite the large decrease in modulus of rigidity. This value increased from 0.87 for the untreated sample to 1.15 for the 10 percent acetic anhydride addition. This trend is shown in Figure 4.7.

4.1.4 Plasticized Gum Arabic

4.1.4.1 Sorbitol

The stress -strain curves for the sorbitol plasticized gum arabic samp;es are shown in Figure AAP3. It was observed that sorbitol plasticized gum arabic had appreciably higher strain at breaK than the untreated gum arabic, but lower modulus of rigidity and UTS. The modulus of rigidity and UTS of the sorbitol plasticized samples dropped drastically. For instance, the modulus dropped from $48.44*10^6 N/m^2$ for unplasticized gum to $7.034*10^6 N/m^2$ for 5 percent sorbitol plasticized gum arabic as shown in Figure 4.8, while the UTS dropped from $12.97*10^5 N/m^2$ for

unplasticized gum arabic to $1.78*10^5 N/m^2$ for 5 percent sorbitol plasticized gum arabic. This trend is shown in Figure 4.9.

The strain at break for the sorbitol plasticized gum arabic samples (Figure 4.10), were quite high and varied from 4,25 for the 3 percent sorbitol addition to over 6.0 for the 5 and 7 percent additive content. Thereafter it decresed for the 10 percent additive content

4.1.4.2 Glycerol

The glycerol plasticized gum arabic samples all exhibited very low UTS and modulus of rigidity but very high strain at break (Figure APP 4). T he modulus of rigidity and UTS of glycerol plastcized gum arabic as observed from Figures 4.11 and 4.12 respectively, showed drastic drop in value. For example the modlus dropped from $48.44*10^6 N/m^2$ for the unplasticized gum arabic to $0.51*10^6 N/m^2$ for the 3 percent glycerol addition while the UTS dropped from $12.97*10^5 N/m^2$ for unplasticized gum arabic to $0.22*10^5 N/m^2$ for the gum arabic containing 3 percent additive. The strain at break, however increased appreciably from 0.87 for unplasticized gum arabic to over 6.0 for 7 percent glycerol content before a decrease was observed for the arabic containing 10 percent glycerol. This trend is shown in Figure 4.13.

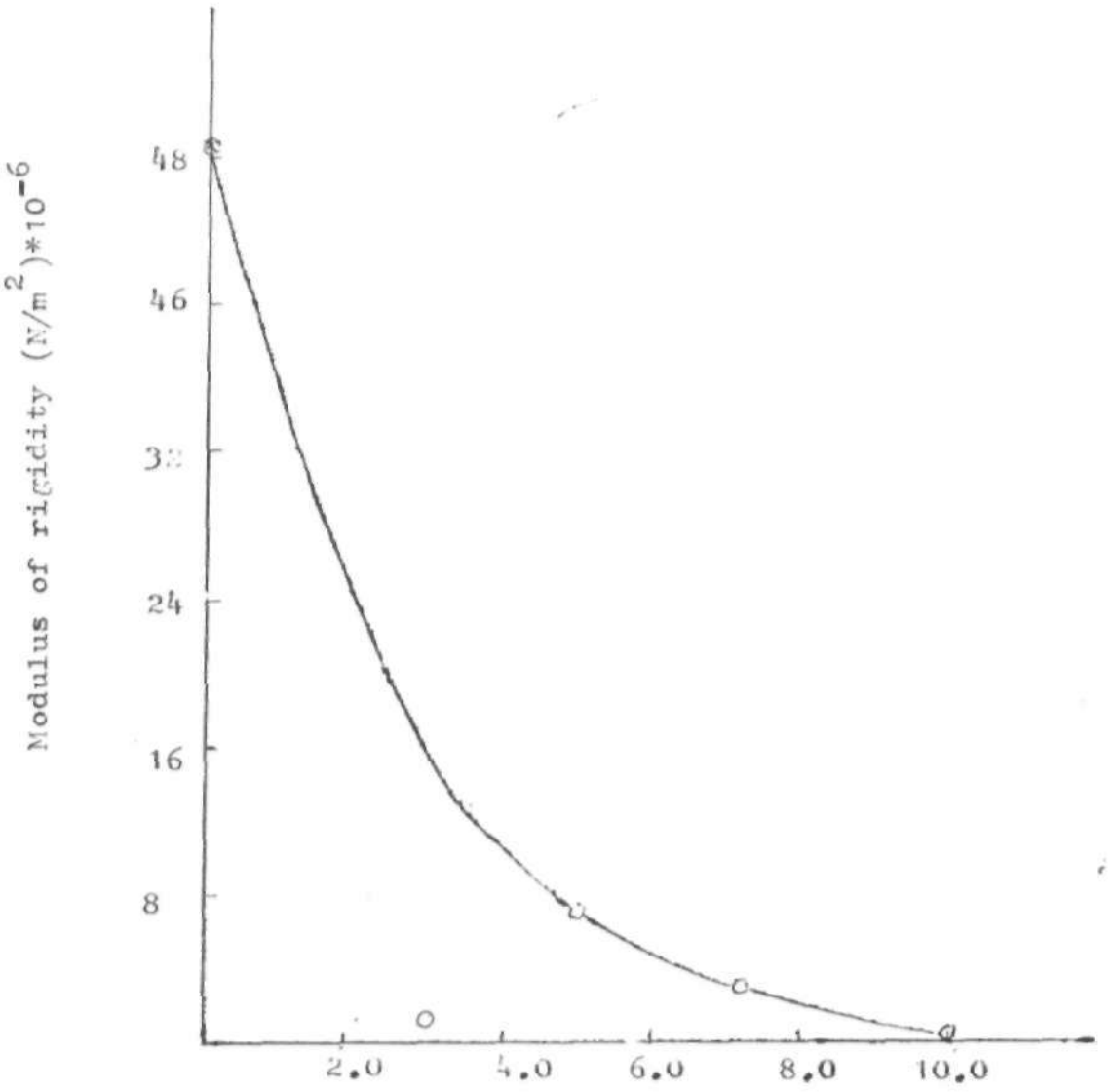


Fig. 4.8: Variation of modulus of rigidity with percent sorbitol in sorbitol plasticized gum arabic.

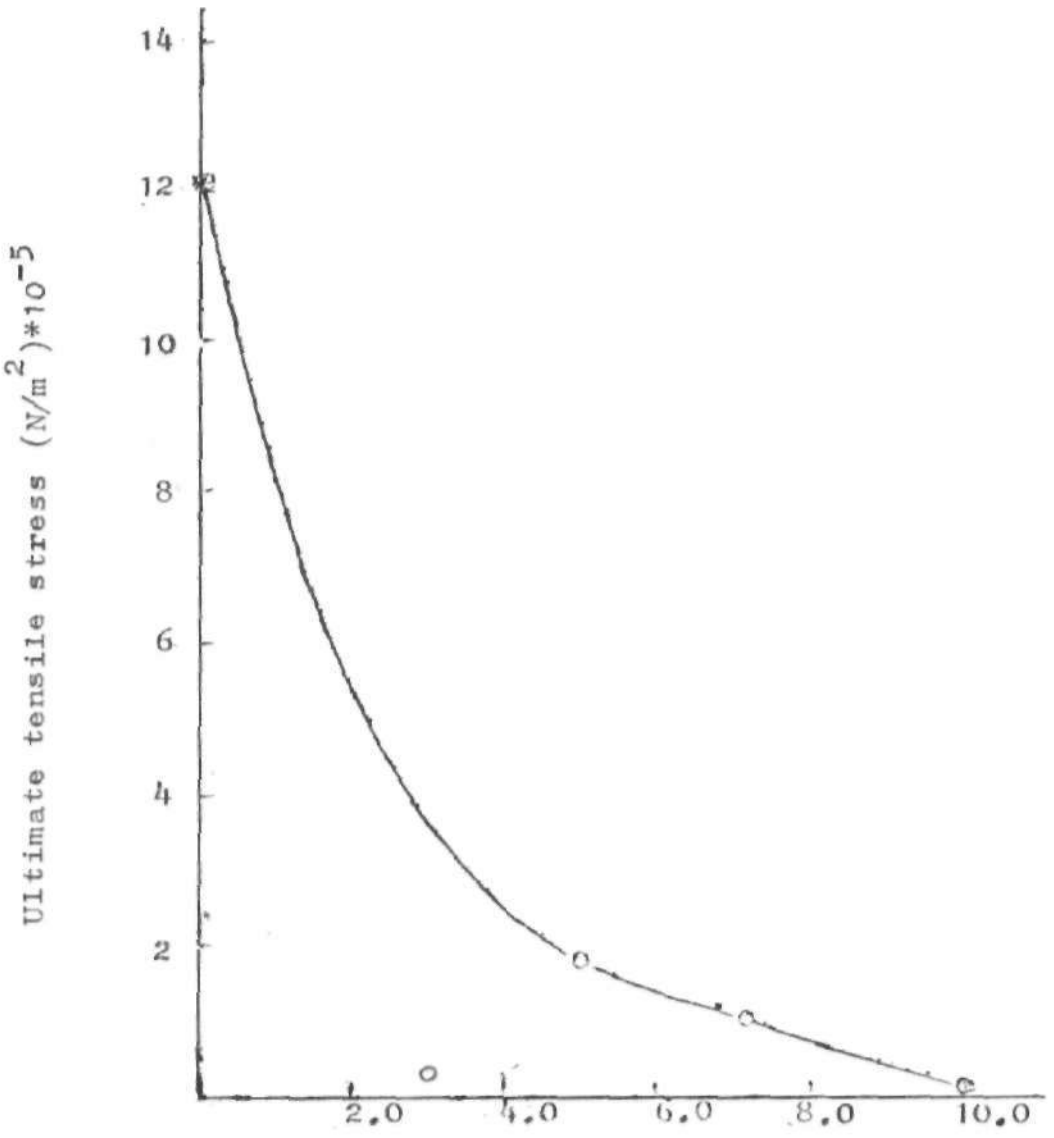


Fig. 4.9: Variation of ultimate tensile stress with percent sorbitol in sorbitol plasticized gum arabic.

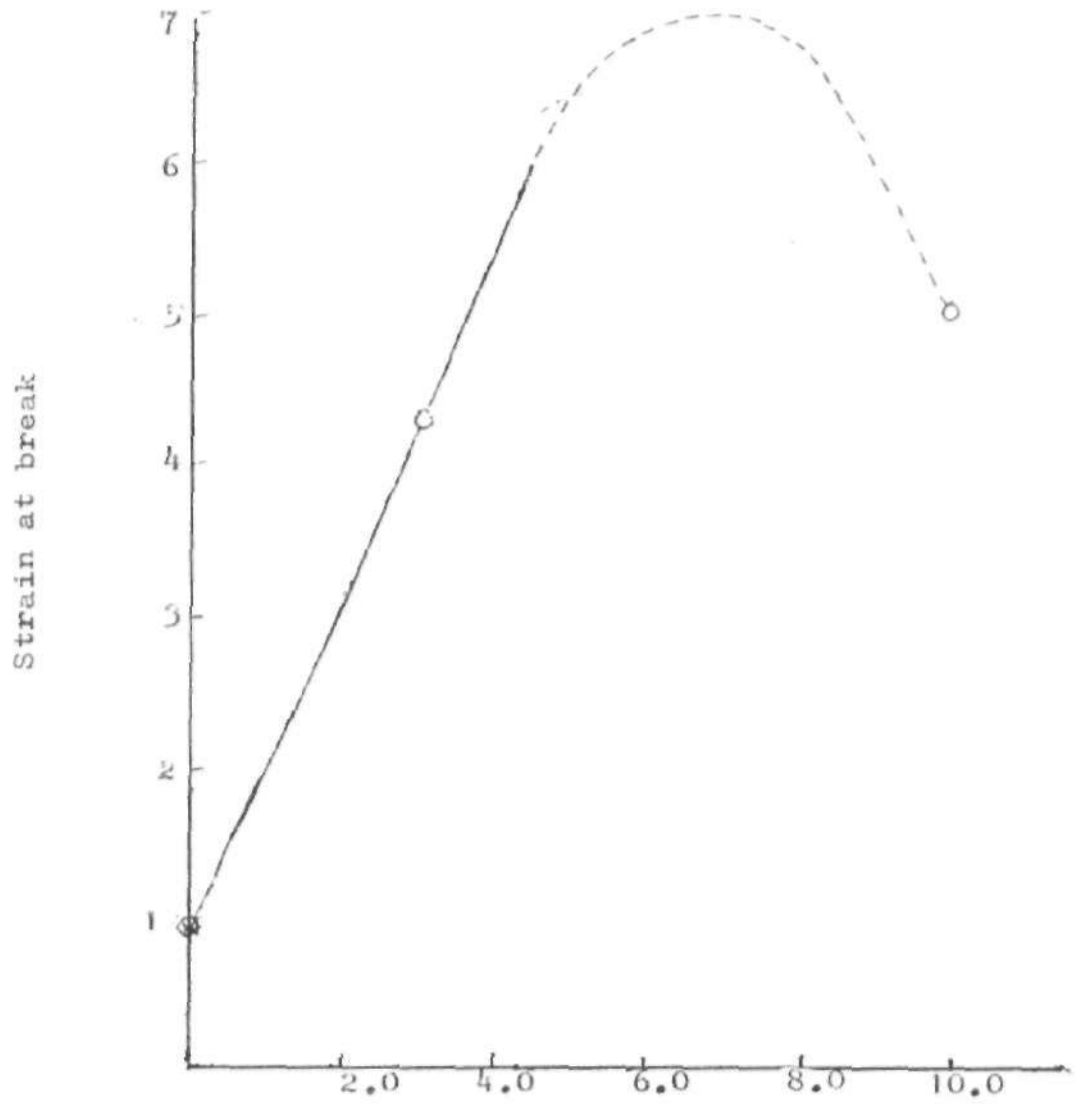


Fig. 4.10: Variation of strain at break with percent sorbitol used in sorbitol plasticized gum arabic.

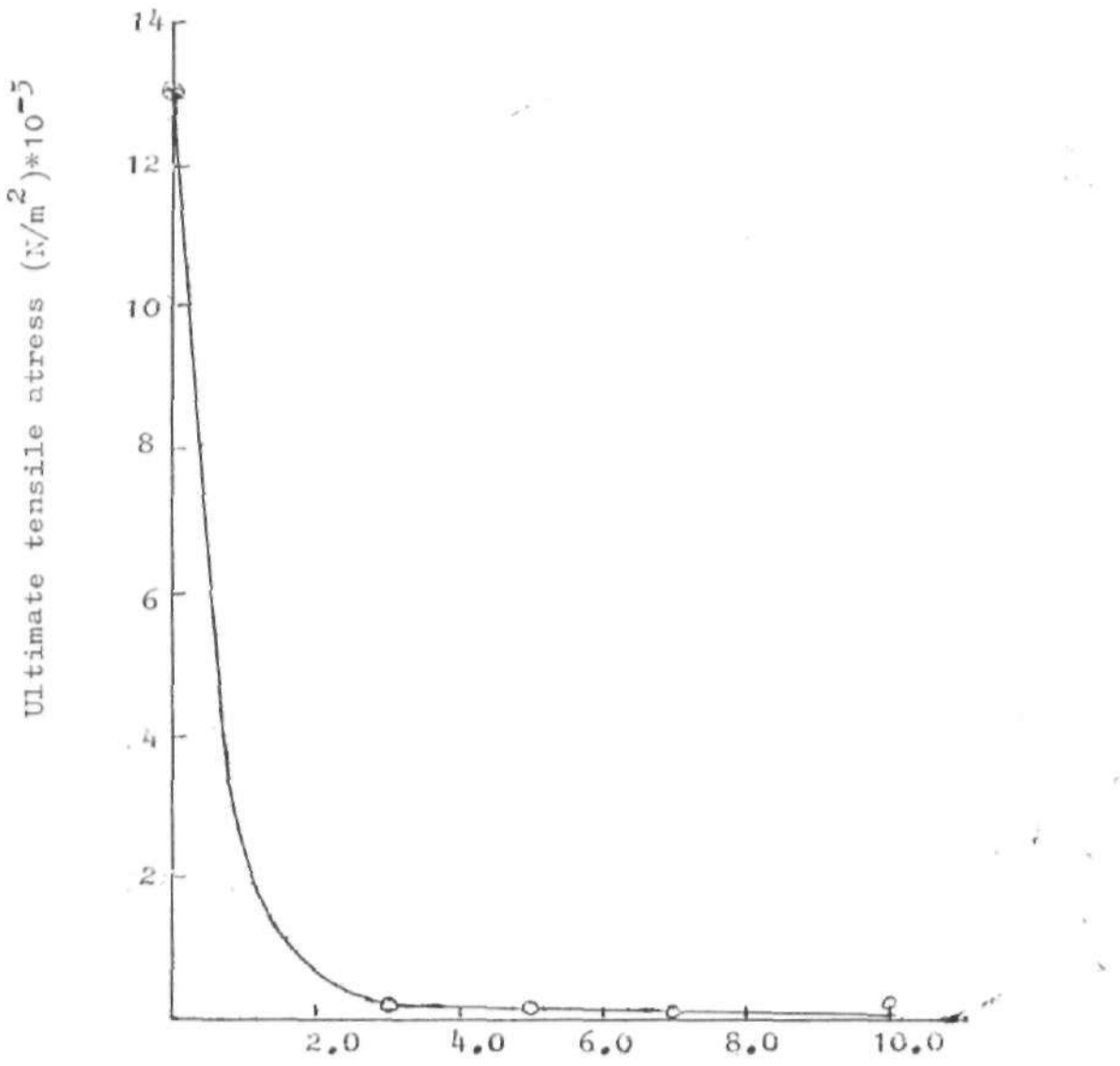


Fig. 4.12: Variation of ultimate tensile stress of glycerol plasticized gum arabic with percent glycerol added.

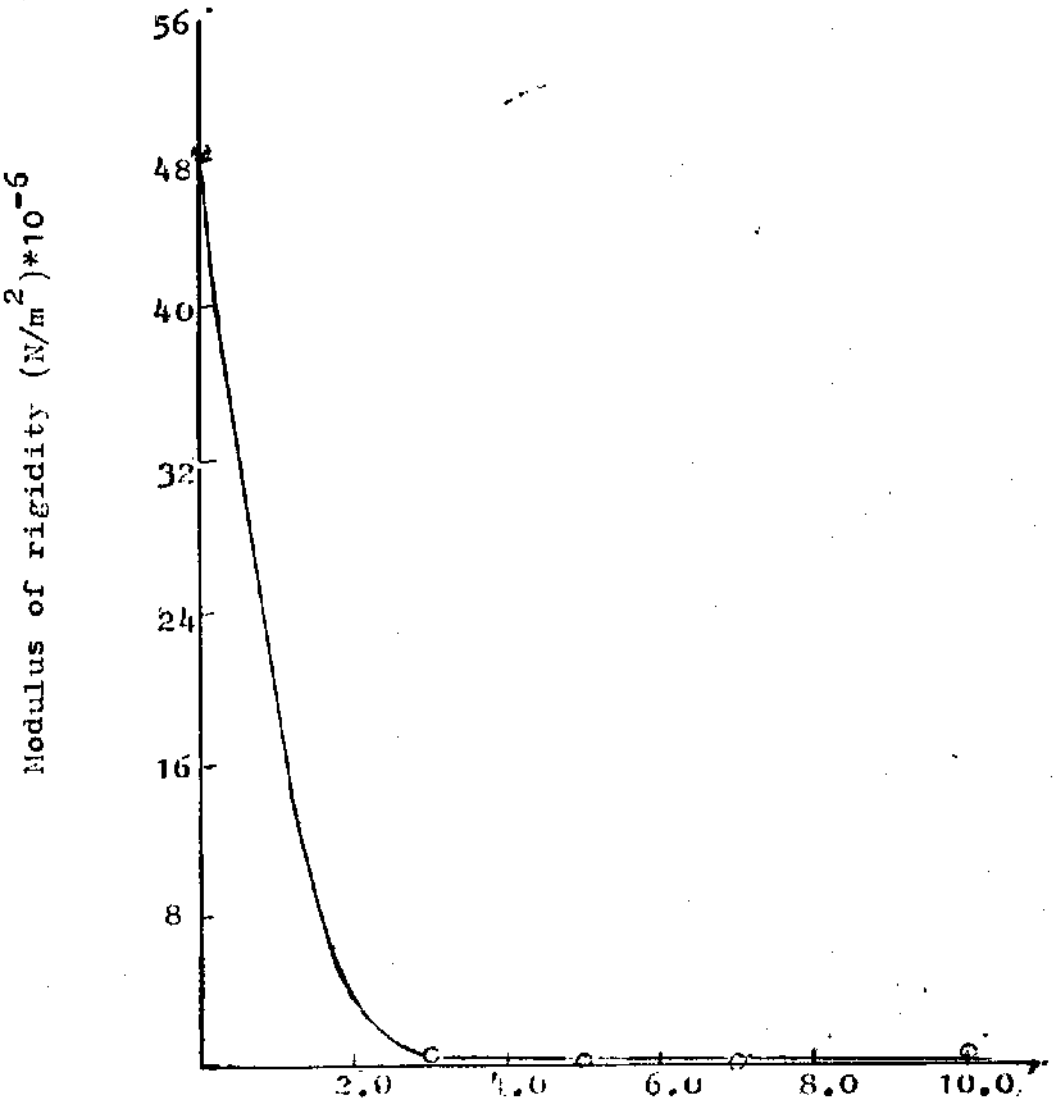


Fig. 4.11: Variation of madulus of rigidity of glycerol plasticized gum arabic with percent glycerol added.

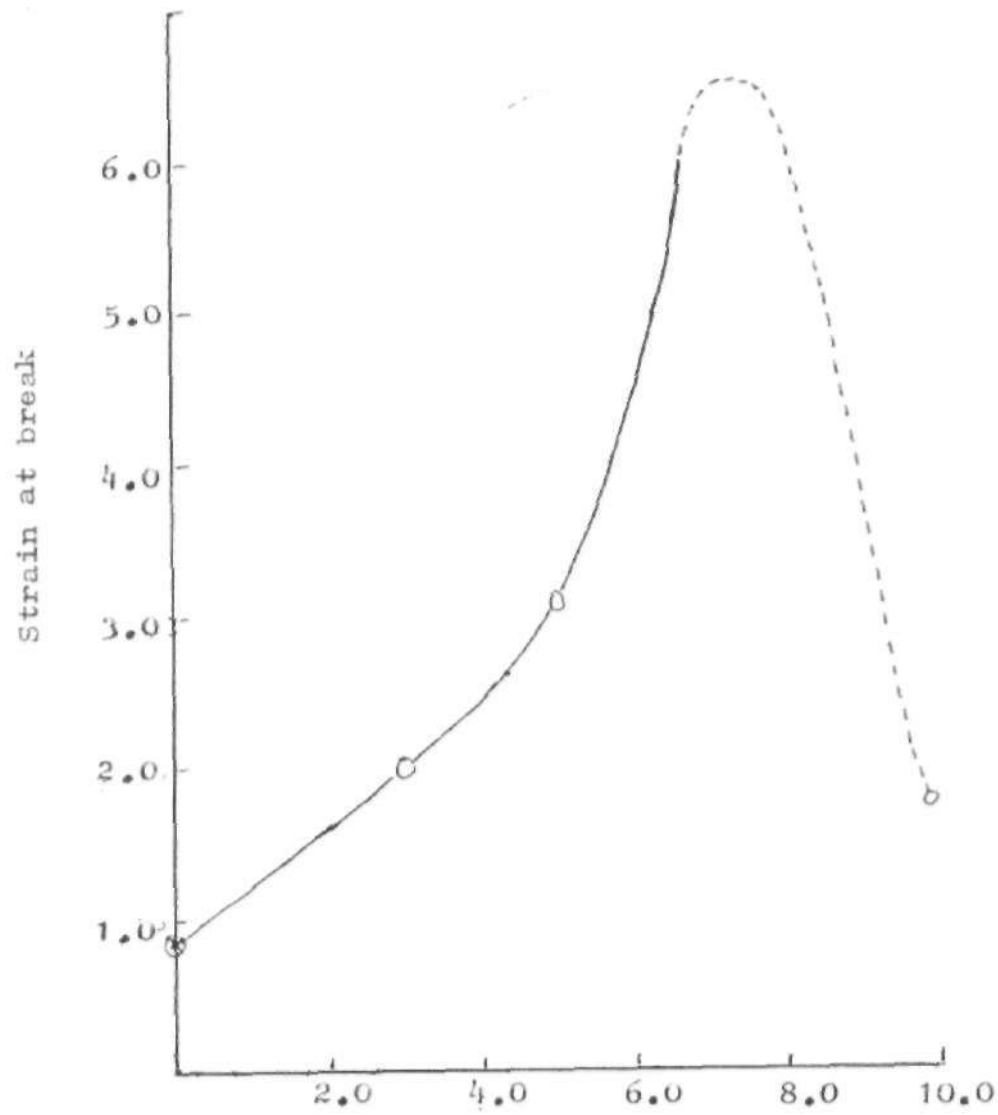


Fig. 4.13: Variation of strain at break of glycerol plasticized gum arabic with percent glycerol us used.

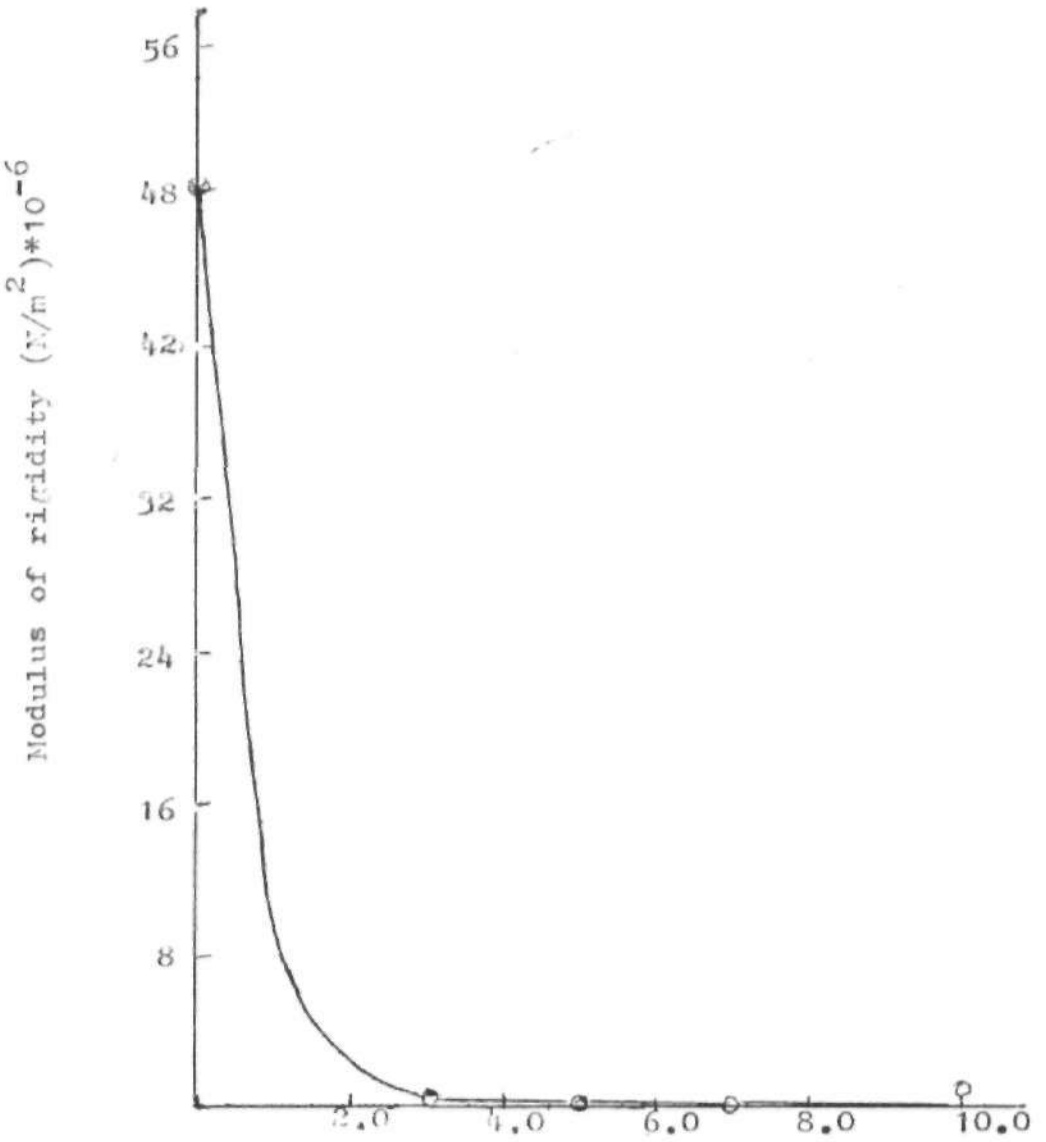


Fig. 4.14: Variation of modulus of rigidity of ethylene glycol plasticized gum arabic with percent ethylene glycol added.

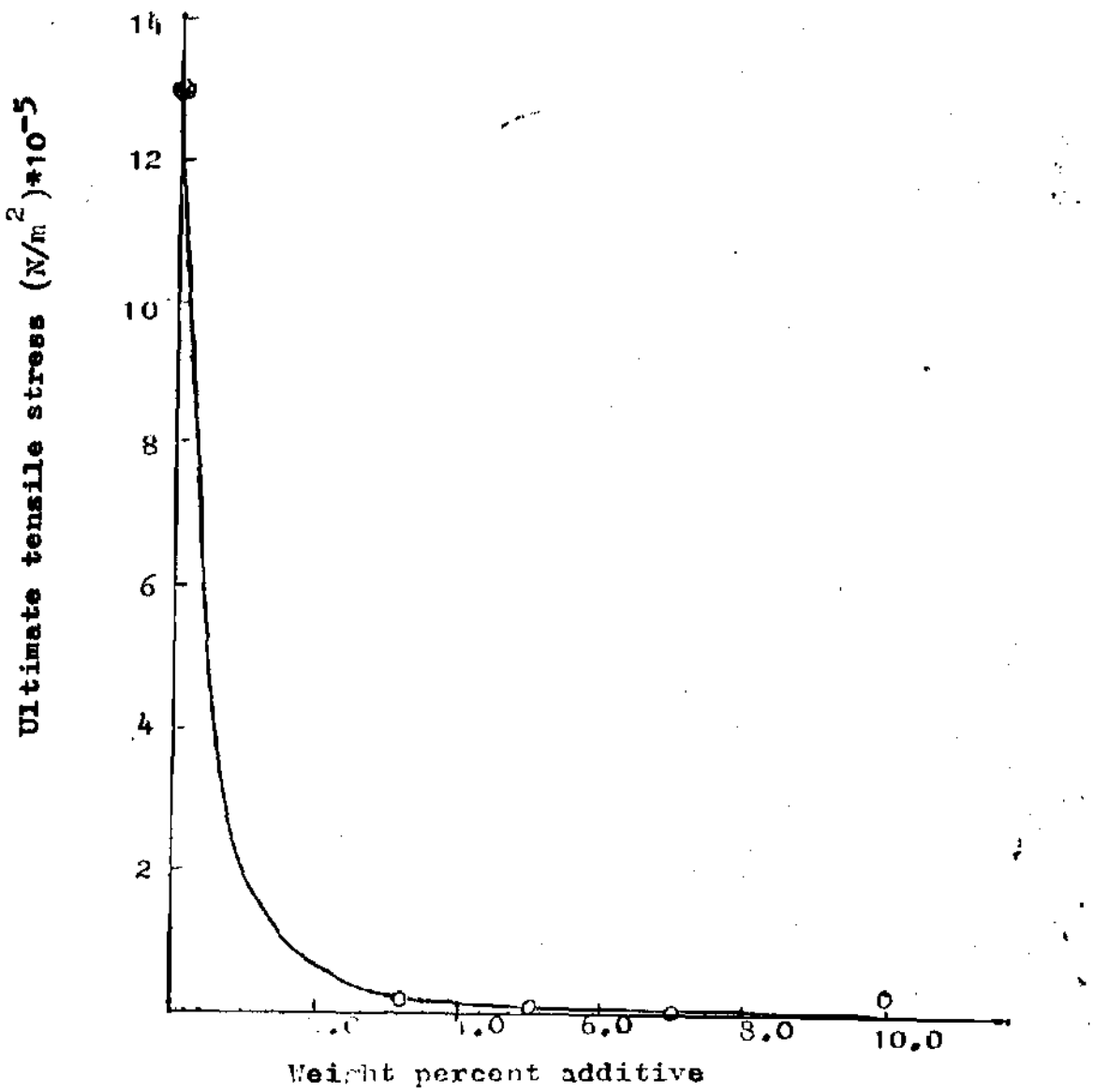


Fig. 4.15: Variation of ultimate tensile stress of ethylene glycol plasticized gum arabic with percent ethylene glycol added.

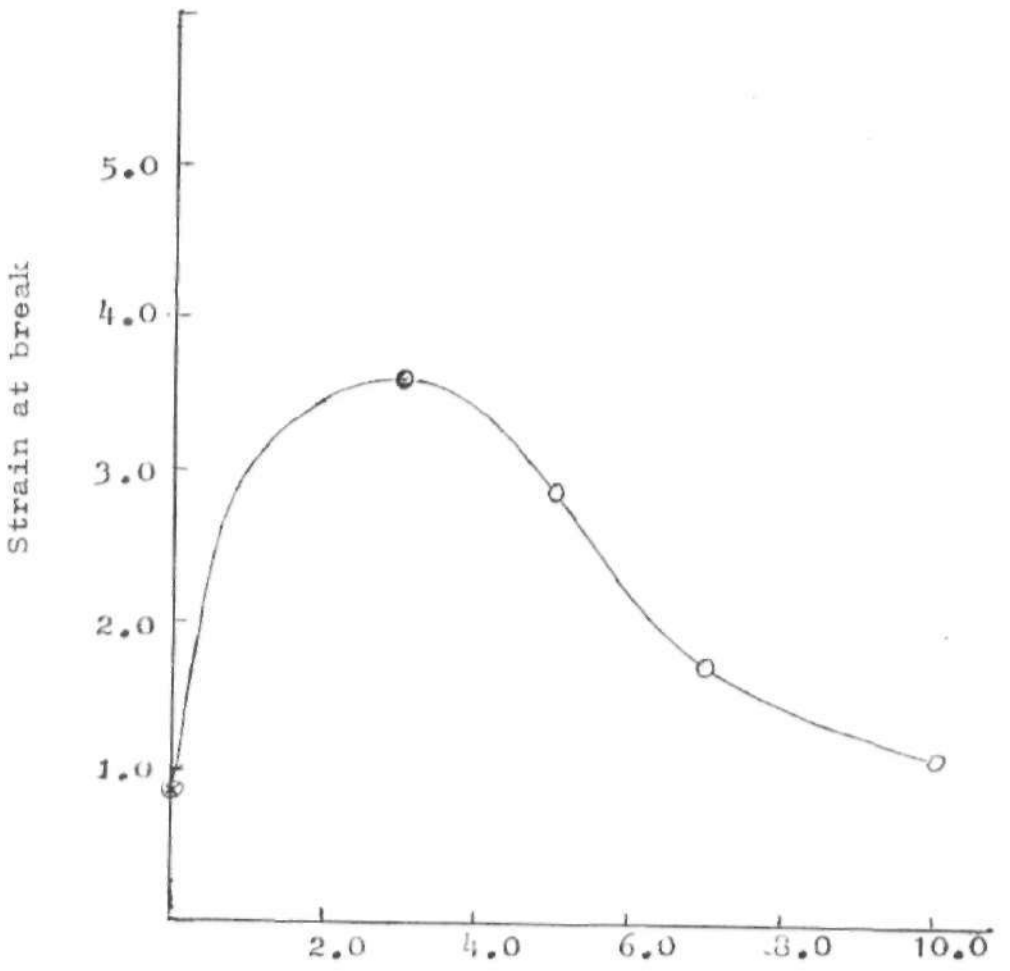


Fig. 4.16: Variation of strain at break of ethylene glycol plasticized gum arabic with percent ethylene glycol used.

4.1.4.3 Ethylene glycol

The ethylene glycol plasticized gum arabicc showed trends very similar to those exhibited by glycerol plasticized gum arabic. The stress-strain analysis curves for these samples are presented in Figure APP5.

The modulii of rigidity and UTS of these samples which are similar to those of glycerol samples, are shown in Figures 4.14 and 4.15.

The strain at break however, differred from glycerol plasticized samples. The observed trend has a peak value of 3.48, which is quite high, at 3 percent ethylene glycol addition. The similarity in results observed for bothethylene glycol and glycerol can be ascribed to similarities in physical propeties. For example their melting points, 291K for glycerol and 260K for ethylene glycol, are comparable. In addition, relative to sorbitol, both are of comparable but smaller molecular sizes.

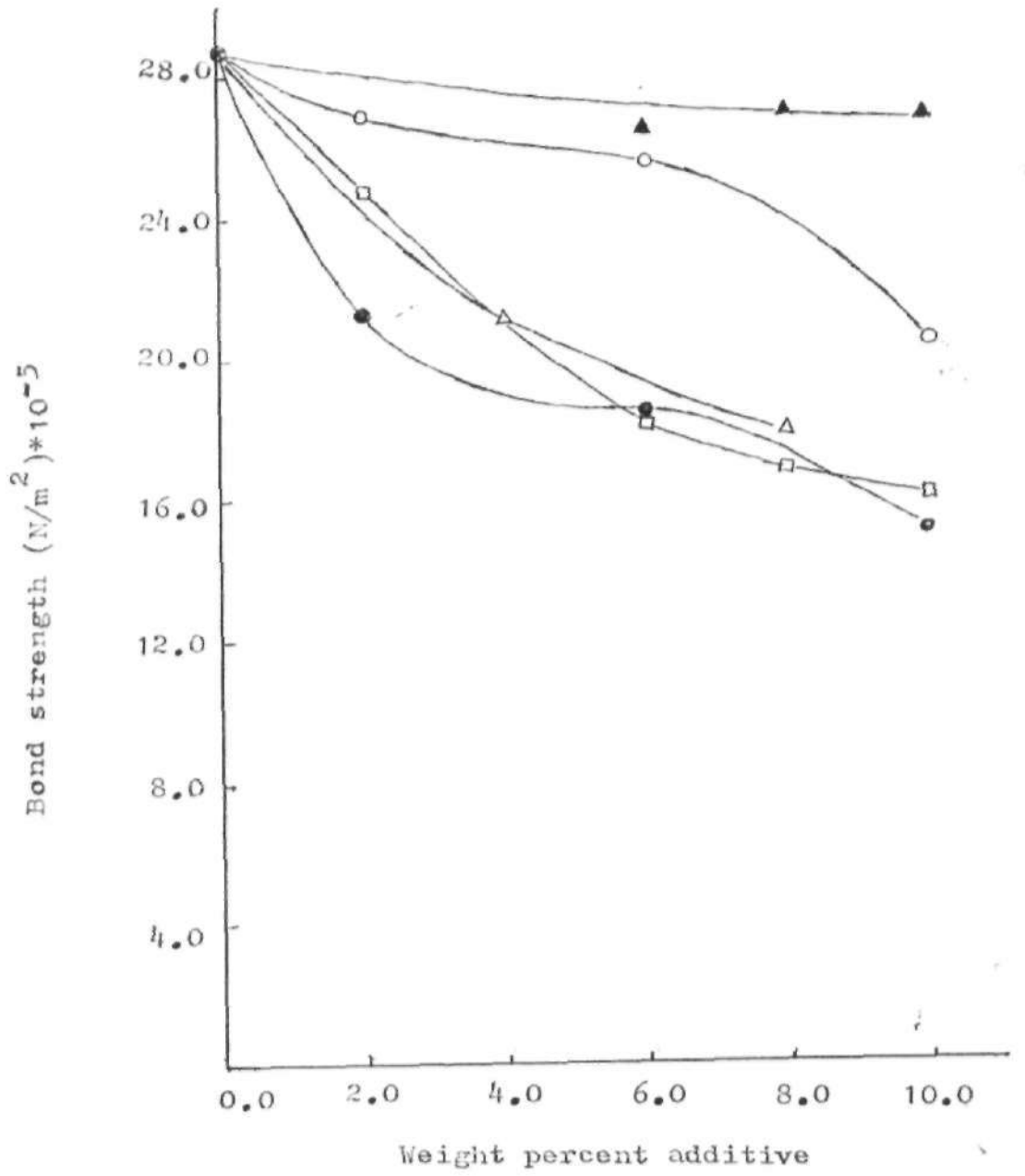


Fig. 4.17: Variation of bond strength with percent additive

4.2 Bond Strength

The results of the bond strength test are shown in Figure 4.17. It was observed that the bond strength of all modified gum arabic samples were lower than of the unmodified gum arabic. In addition, bond strengths were observed to decrease with increasing content of the additive. Of all the modified systems, the ethylene glycol plasticized gum arabic gave the highest bond strength whilst the glycerol plasticized gum arabic had the blowest bond strength values. The relative variation shown between all the modified system is unclear but the gradual decrease in bond strength with additive content suggests that formation of less rigid structures do nt support a high interfacial attraction necessary to achieve high bond strength. This is particularly observed from the trend shown by both the acetolysed and acetate derivative samples. The latter gave lower bond strength. The unclear behaviour may also not be unconnected with the fact that in all cases, the bond strengths observed, appeared not be a real test for the bond strength as failure occurred not in the glue line but in the adherends. This feature is characteristic of all good adhesives although in this work, it disallowed a

proper understanding of the relative effets of the different modification methods undertaken.

4.3 Discussion

4.3.1 Plasticized systems

The results have shown that the hard and brittle stress-strain relationship typical of the unplasticized gum arabic can be modified by the addition of plasticizing agents. The effect of the additives was manifested in the decrease in values for both the modulus of rigidity and ultimate tensile stress relative to the unplasticized gum arabic. The additive also increased the strain at break values for the plasticized systems. Thus the film produced from these plasticized systems were not only moore flexible but were also tougher than the unplasticized gum arabic. They were able to this by penetrating between the polymer chains there by allowing for easier chain movements relative to one another. The results showed that the larger the size of the plasticizer the more flexible is the film. Similarly, the higher the number of polar hydroxyl groups, the more flexible is the film thus sorbitol, $CH_2OH(C_4H_8O_4)CH_2OH$, which has the best of these two properties produced the toughest of the plasticized systems. Glycerol, $CH_2OH.CHOH.CH_2OH$

and ethylene glycol($CH_2OH)_2$ both of comparable size and polarity, similarly produced plasticized systems of comparable toughness and flexibilty.

4.3.2 Chemically modified Gum arabic

The expected results from the chemical modification are based on the fragmentation pattern expected from gum arabic after chemical treatment. The stress-strain curve exhibited by gum arabic can be linked to its relatively high molecular weight in addition to the rigid backbones. Possession of branch linkages would also add to the rigid nature of the fum. The result of this is that when cast into a film, it is very brittle and thus its main drawback in adhesive formulations. Therefore it is believed that scission of these linkages might result in low molecular weight structures which will reduce the rigidity inherent in the structure.

There are two main structural linkages that are susceptible to bond scission. These are the main backbone chain of (1-3) linked D-galactopyranose units and the branching or substitution of these units at the C-6 position with various chains.

The main structural backbone link is known to be susceptible to acid hydrolysis whilst being resistant to acetolysis. The branch (1-6) linkages are however known to resist acid hydrolysis but are easily broken by acetolysis. Thus the very low viscosity of the medium observed after hydrolysis could be attributed to extensive chain deformation of the backbone to give rise to acidic oligosaccharide fragments. Only at mild condition of acid concentration (3 weight percent acid) was the hydrollysis appeared to be limited. Even at this low concentration, the product of hydrolysis produced films that gave low values of modulus of rigidity and ultimate tensile stress but highly flexible structure.

The acetolysed gum arabic was observed to exhibit higher values of modulus of rigidity and ultimate tensile stress than the other chemically modified gum arabic. This may be because scissions in the acetolysed system only occurred at branch points. The effect is debranching which results in reduction of chain rigidity and proper re-allignment of molecules, as gum arabic backbone molecules are now able to move relative to one another.

The results observed for the acetate derivative of gum arabic also implied debranching of the chains. The effect is however, unlike in the acetolysed samples, probably limited because of the presence of the acetate group. The re-allignment of molecules with the slight polar nature of acetate group might have increased the intermolecular force of attractioin, the result of which is tougher material than the untreated gum arabic. It is therefore suggested that the acetate group, though capable of reducing modulus of rigidity, might not appreciably increase the strain at break of gum arabic, probably due to overshadowing effect of the acetate groups.

On comparative effectiveness, the acetolysed gum arabic was found to be the strongest and toughest of the chemically modified samples. This follows from the fact that the product of acid hydrolysis was a very low molecullar weight mass which did not produce films of any adhesive usefulness. For the acetate derivative, the induced intermolecular attractionm caused by the acetate group also decreased its *effectiveness by producing films that were slightly* rigid and therefore more brittle than the acetolysed samples.

4.3.3 Comparison of physically and chemically modified Gum arabic

It appears that generally, the adhesive produced from chemically modified gum arabic showed better adhesive performance (i.e. good modulus of rigidity, ultimate tensile stress, and strain at break) than the physically modified samples. This may be due to the fact that the effective modification of the mechanical properties in the physically modified samples are cosmetic, i.e. superfacial, having only to do with interactions between molecular chains. Chemically modified samples might however have produced newe re-allignment of inter and intra molecular forces of attraction which will produce fundamental changes in the mechanical properties.

The acetolysed sample was, from the foregoing, found to possess the best adhesive properties.

CONCLUSIONS

Gum arabic has been physically and chemically modified to give a more flexible and tougher film than the untreated gum arabic. They all showed lower bond strengths.

This work revealed that the modulus of rigidity and ultimate tensile stress for all modified samples were lower than for untreated gum arabic with the chemically modified samples exhibitng higher values than the physically modified samples. The bond strengths for all the modified samples were also found to be lower than for the unmodified samples. The strain at break values for the modified samples were however higher than for the unmodified ones with the physically modified samples exhibiting appreciably higher strain at break values than the chemically modified ones.

Of the physically modified samples, sorbitol plasticized gum arabic (with 3% sorbitol) was found to have the best adhesive properties while for the chemically modified samples, the acetolysed gum arabic at about 5-7 weight percent was observed to have the best adhesive properties.

The chemically modified gum arabic samples generally had better adhesive properties than the physically modified samples. On comparative effectiveness, the acetolysed gum arabic was therefore found to be the strongeat with overall best adhesive adhesive properties at 6 weight percent acetolyser addtion.

RECOMMENDATIONS

The following areas are some areas where more research works could be done viz.

(i) A comprehensive survey on production and utilization of adhesives in Nigeria. This will shed more light on the production short fall or otherwise of adhesives in Nigeria, it will also enable identification of other types of adhesives that could be researchee into.

(ii) A study on the effect of fillers on adhesive performance of chemically treated gum arabic to help see if fillers which cost less than gum arabic could be used to produce good quality gum.

(iii) A scale up of the production of chemically modified gum arabic based on the results of the study on effect of fillers on gum arabic. The necessary items and equipments should locally producable.

APPENDIX 1

Table AP1.1: Stress-strain analysis data for sulphuric acid hydrolysed gum arabic (3%)

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
3.5244	52	.014	1.0	.0397	1.92
		.026	3.0	.0738	5.71
		.040	9.0	.1136	17.31
		.043	17.0	.1363	32.69
		.052	23.0	.1476	44.23
		.056	29.0	.1590	55.77
		.066	43.0	.1874	82.69
		.084	61.0	.2385	117.31
		.094	69.0	.2669	132.69
		.108	79.0	.3066	151.92
		.116	85.0	.3293	163.46
		.121	89.0	.3435	171.15
		.123	94.0	.3492	180.71
		.120	96.0	.3406	184.75
		.108	97.0	.3066	186.54

Table AP1.2: Stress-strain analysis data for untreated gum arabic.

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.043	52	1.90	1.0	9.30	1.92
		2.20	2.0	10.77	3.85
		2.50	4.0	12.24	7.69
		2.60	6.0	12.73	11.54
		2.65	10.0	12.97	19.23
		2.60	15.0	12.73	28.85
		2.40	23.0	11.75	44.23
		2.20	32.0	10.77	59.62
		2.00	38.0	9.79	73.08
		1.80	45.0	8.81	86.54

Table AP1.3: Stress-strain analysis data for 3% acetolyser treatment of gum arabic.

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
3.97	52	2.000	1.0	5.48	1.92
		2.800	3.0	7.67	5.77
		3.100	9.0	8.49	13.46
		2.800	17.0	7.67	32.69
		2.400	27.0	6.58	51.92
		2.000	41.0	5.48	58.85
		1.800	51.0	4.93	98.08
		1.600	61.0	4.38	117.31
		1.400	67.0	3.84	128.85
		1.100	69.0	3.01	132.60

Table AP1.4: Stress-strain analysis data for 5% acetolyser treatment of gum arabic.

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.092	85	1.20	1.0	6.22	1.18
		1.35	2.0	6.99	2.35
		1.48	4.0	7.67	4.71
		1.50	7.0	7.77	8.24
		.90	30.0	4.66	35.26
		.70	44.0	3.63	51.76
		.60	56.0	3.11	65.88
		.40	80.0	2.07	94.12
		.20	86.0	1.04	101.18
		.10	89.0	.52	104.71

Table AP1.5: Stress-strain analysis data for 7% acetolyser treatment of gum arabic.

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.025	52	1.10	1.0	5.43	1.92
		1.30	2.0	6.42	3.85
		1.42	5.0	7.01	9.62
		1.30	11.0	6.42	21.15
		1.20	14.0	5.93	26.92
		1.10	18.0	5.43	34.62
		.80	34.0	3.95	65.38
		.60	43.0	2.96	82.69
		.35	46.0	1.73	88.46
		.15	48.0	.74	92.31

Table AP1.6: Stress-strain analysis data for 10% acetolyser treatment of gum arabic.

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
4.043	52	.90	2.0	2.23	3.85
		1.08	4.0	2.67	7.69
		1.10	6.0	2.72	11.54
		.90	14.0	2.23	26.92
		.80	18.0	1.98	34.62
		.70	24.0	1.73	46.15
		.60	34.0	1.48	65.38
		.50	52.0	1.24	100.00
		.40	94.0	.99	180.77
		.20	101.0	.49	194.23

Table AP1.7: Stress-strain analysis data of gum arabic samples treated with 3% acetic anhydride.

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
3.0238	85	1.40	1.0	4.62	1.18
		1.75	2.0	5.78	2.35
		1.95	4.0	6.44	4.71
		2.05	8.0	6.77	9.41
		2.00	12.0	6.61	14.12
		1.90	16.0	6.27	18.82
		1.70	23.0	5.61	27.06
		1.40	35.0	4.62	41.18
		1.20	46.0	3.96	54.12
		.90	74.0	2.97	87.06
		.45	107.0	1.49	125.88

Table AP1.8: Stress-strain analysis data of gum arabic samples treated with 5% acetic anhydride.

Area $(m2)*10^5$	Gauge length $(m)*10^3$	Load (kg)	Extension $(m)*10^3$	Stress $(N/m2)*10^{-5}$	Strain $*10^2$
3.976	85	.80	1.0	2.69	1.18
		.95	2.0	3.19	2.35
		1.00	4.0	3.36	4.71
		.90	10.0	3.02	11.76
		.70	18.0	2.35	21.18
		.50	34.0	1.68	40.00
		.40	50.0	1.34	58.82
		.30	76.0	1.01	89.51
		.23	80.0	.77	94.12

Table AP1.9: Stress-strain analysis data of gum arabic samples treated with 7% acetic anhydride.

Area $(m2)*10^5$	Gauge length $(m)*10^3$	Load (kg)	Extension $(m)*10^3$	Stress $(N/m2)*10^{-5}$	Strain $*10^2$
3.132	52	1.50	1.0	4.64	1.92
		1.80	2.0	5.56	3.85
		1.90	4.0	5.87	7.69
		1.80	9.0	5.56	17.31
		1.70	11.0	5.25	21.15
		1.50	16.0	4.64	30.77
		1.10	33.0	3.40	63.46
		.80	43.0	2.47	82.69
		.43	48.0	1.33	92.31
		.30	51.0	.93	94.12

Table AP1.10: Stress-strain analysis data of gum arabic samples treated with 10% acetic anhydride.

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
3.077	52	1.20	1.0	3.90	1.92
		1.35	2.0	4.46	3.85
		1.43	4.0	4.73	7.69
		1.40	7.0	4.63	13.46
		1.20	13.0	3.90	25.00
		1.00	21.0	3.31	40.38
		.70	35.0	2.31	67.31
		.60	39.0	1.98	75.00
		.45	41.0	1.49	78.85
		.20	42.0	.66	80.77

Table AP1.11: Stress-strain analysis data of 3% sorbitol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
3.225	52	.034	2.0	.153	3.85
		.046	4.0	.207	7.69
		.058	10.0	.261	19.23
		.062	16.0	.279	30.77
		.064	26.0	.288	50.00
		.064	50.0	.288	96.15
		.060	94.0	.270	180.77
		.054	134.0	.243	257.69
		.048	221.0	.153	425.00

Table AP1.12: Stress-strain analysis data of 5% sorbitol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
1.8	85	.15	1.0	.83	1.18
		.20	3.0	1.11	3.53
		.25	9.0	1.25	10.59
		.30	19.0	1.67	22.35
		.32	39.0	1.78	45.88
		.32	79.0	1.78	92.94
		.25	193.0	1.25	227.06

Table AP1.13: Stress-strain analysis data of 7% sorbitol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.867	85	.10	1.0	.35	1.18
		.20	5.0	.70	5.88
		.25	10.0	.87	11.77
		.30	30.0	1.05	35.29
		.25	120.0	.87	141.18
		.20	210.0	.70	247.06

Table AP1.14: Stress-strain analysis data of 10% sorbitol plasticized gum arabic

Area $(m2)*10^5$	Gauge length $(m)*10^3$	Load (Kg)	Extension $(m)*10^3$	Stress $(N/m2)*10^{-5}$	Strain $*10^2$
2.856	52	.018	1.0	.069	1.92
		.024	3.0	.092	5.77
		.028	5.0	.107	9.62
		.034	17.0	.130	32.69
		.036	39.0	.136	75.00
		.034	65.0	.130	125.00
		.032	77.0	.122	148.08
		.028	85.0	.107	163.46
		.026	95.0	.099	182.69
		.022	117.0	.084	225.00

Table AP1.15: Stress-strain analysis data of 3% glycerol plasticized gum arabic

Area $(m2)*10^5$	Gauge length $(m)*10^3$	Load (Kg)	Extension $(m)*10^3$	Stress $(N/m2)*10^{-5}$	Strain $*10^2$
2.34	52	.023	1.0	.098	1.92
		.030	2.0	.128	3.85
		.034	3.0	.145	5.77
		.048	14.0	.205	26.92
		.050	20.0	.214	38.46
		.051	33.0	.220	63.46
		.050	45.0	.214	86.54
		.040	79.0	.171	151.92
		.026	101.0	.111	194.23
		.020	102.0	.085	196.15

Table AP1.16: Stress-strain analysis data of 5% glycerol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.532	52	.014	1.0	.055	1.92
		.020	4.0	.079	7.69
		.022	7.0	.087	13.46
		.024	15.0	.095	28.85
		.024	29.0	.095	55.74
		.022	55.0	.087	105.77
		.020	95.0	.079	182.69
		.018	125.0	.071	240.38
		.014	153.0	.055	294.23
		.010	161.0	.040	309.62

Table AP1.17: Stress-strain analysis data of 7% glycerol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.756	52	.006	2.0	.022	3.85
		.008	12.0	.029	23.07
		.008	38.0	.029	73.08
		.006	110.0	.022	211.54
		.004	224.0	.015	430.77

Table AP1.18: Stress-strain analysis data of 10% glycerol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.645	52	.028	1.0	.106	1.92
		.038	2.0	.144	3.85
		.048	5.0	.182	9.62
		.054	8.0	.204	15.38
		.056	12.0	.212	23.08
		.057	22.0	.216	42.31
		.052	54.0	.197	103.85
		.040	67.0	.151	128.85
		.022	76.0	.088	146.15
		.020	79.0	.076	151.92

Table AP1.19: Stress-strain analysis data of 3% ethylene glycol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.868	52	.028	1.0	.098	1.92
		.056	3.0	.195	5.77
		.058	5.0	.202	9.62
		.047	18.0	.164	34.62
		.042	27.0	.146	51.92
		.024	85.0	.084	163.46
		.018	126.0	.063	242.31
		.014	159.0	.049	305.77
		.011	185.0	.038	355.77

Table AP1.20: Stress-strain analysis data of 5% ethylene glycol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.673	52	.017	1.0	.064	1.92
		.022	3.0	.082	5.77
		.024	8.0	.090	15.38
		.022	17.0	.082	32.69
		.020	23.0	.075	44.23
		.016	38.0	.060	73.08
		.010	79.0	.037	151.92
		.006	121.0	.022	232.69
		.004	141.0	.015	271.15
		.002	148.0	.008	284.62

Table AP1.21: Stress-strain analysis data of 7% ethylene glycol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.629	52	.006	1.0	.023	1.92
		.015	2.0	.057	3.85
		.020	3.0	.076	5.77
		.024	6.0	.091	11.54
		.020	14.0	.076	26.92
		.018	17.0	.069	32.69
		.014	25.0	.053	48.08
		.010	38.0	.038	73.08
		.006	58.0	.023	111.54
		.004	60.0	.015	115.38
		.002	70.0	.008	134.62

Table AP1.22: Stress-strain analysis data of 10% ethylene glycol plasticized gum arabic

Area (m2)*10^5	Gauge length (m)*10^3	Load (Kg)	Extension (m)*10^3	Stress (N/m2) *10^{-5}	Strain *10^2
2.769	52	.044	1.0	.159	1.92
		.062	2.0	.224	3.85
		.068	3.0	.246	5.77
		.076	8.0	.275	15.38
		.078	12.0	.282	23.08
		.076	20.0	.275	38.46
		.062	35.0	.224	67.31
		.045	46.0	.163	88.46
		.031	53.0	.112	101.92
		.026	55.0	.094	105.72

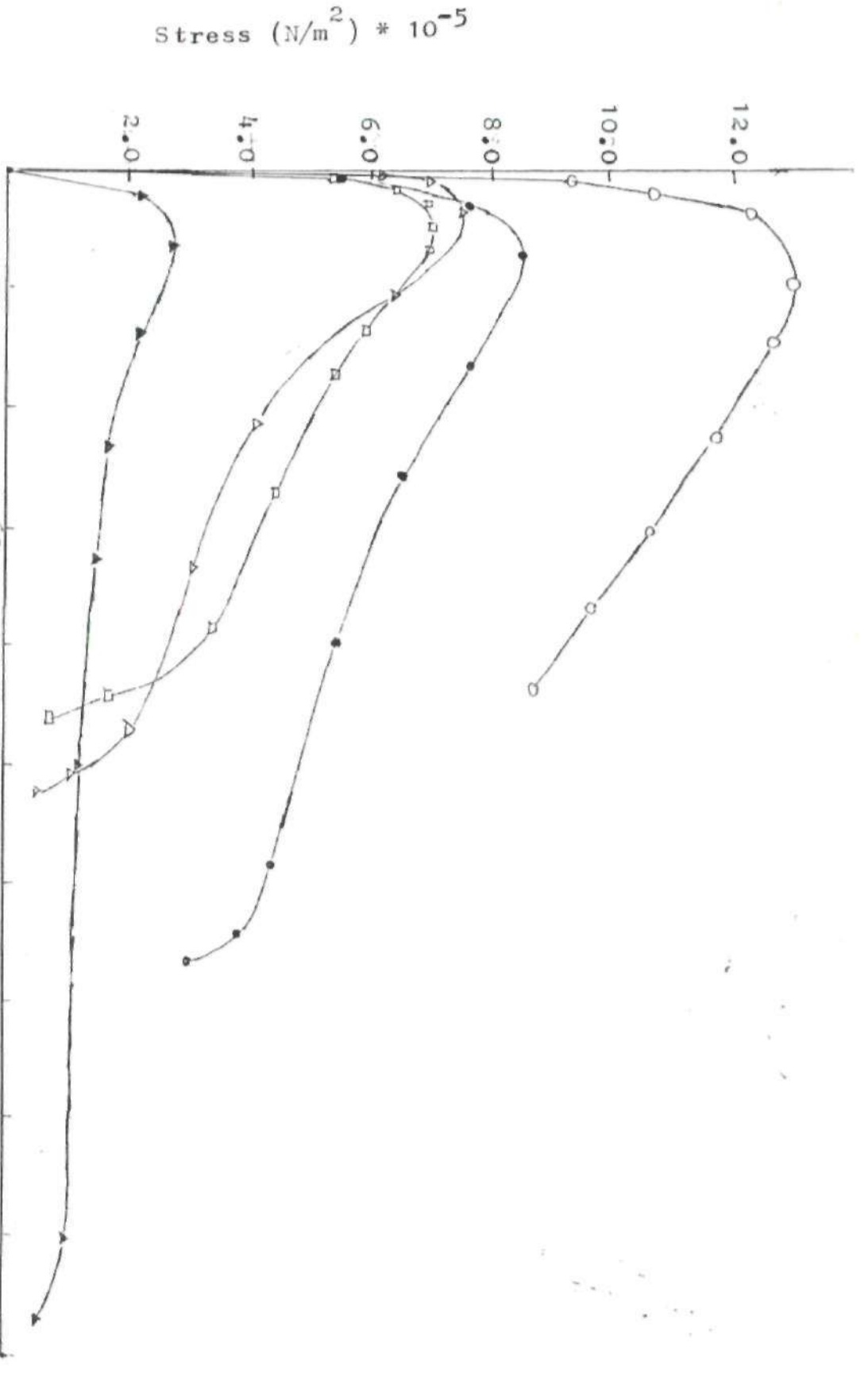


Fig. APP 1: Stress strain curves for acetolysed gum arabic

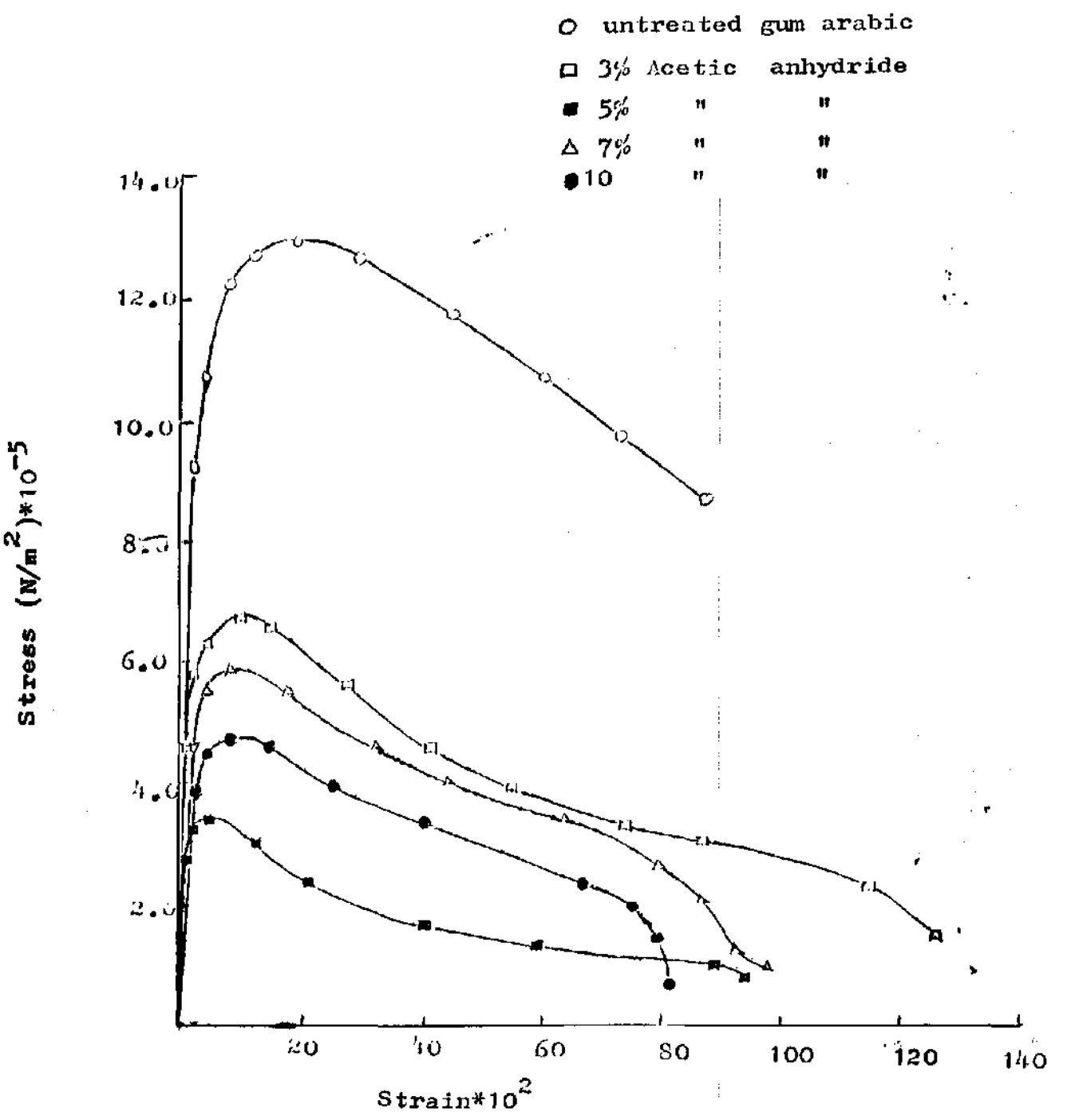


Fig. APP2: Stress strain curves for samples of gum arabic acetate derivative.

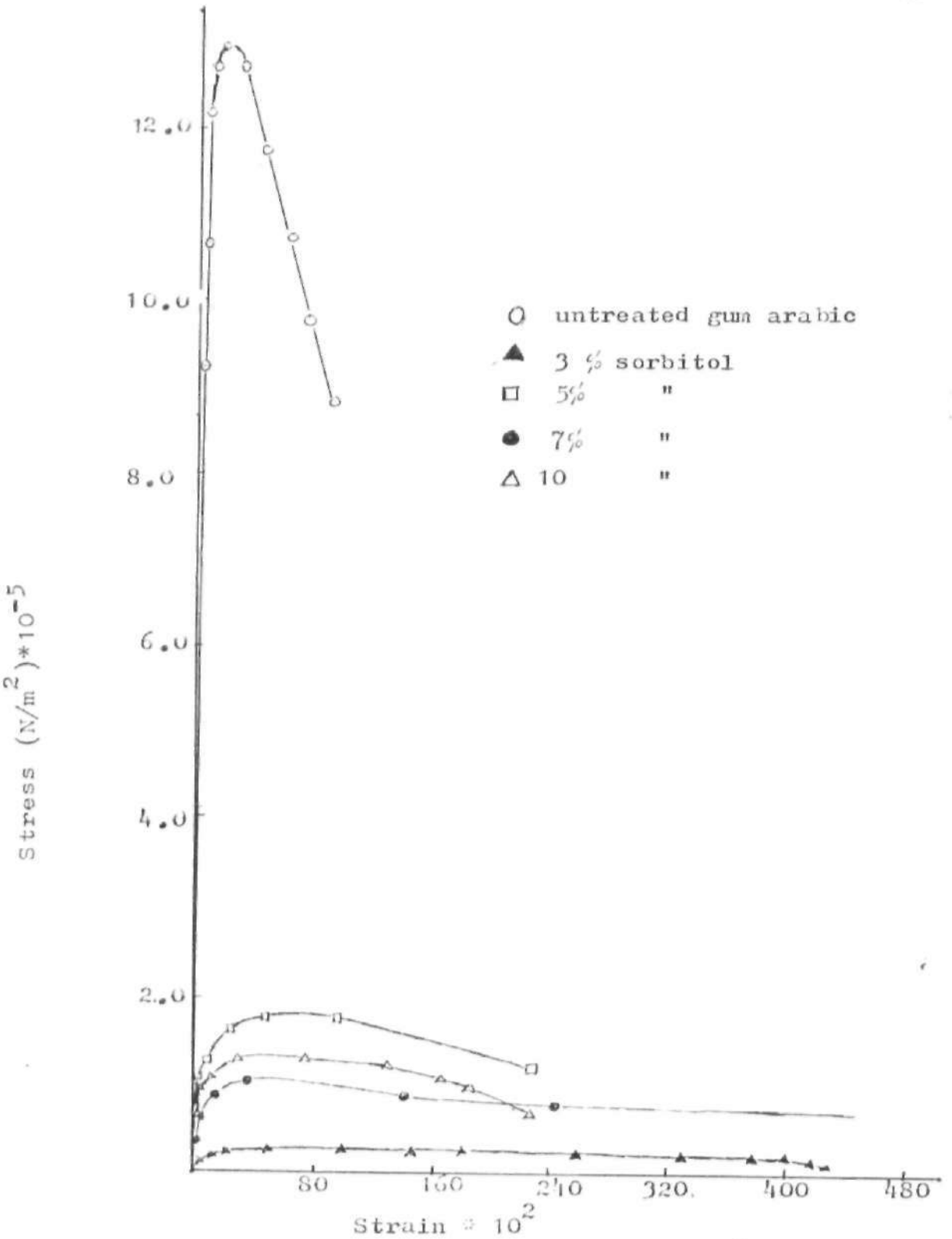


Fig. APP3: Stress strain curves for sorbitol plasticized gum arabic samples.

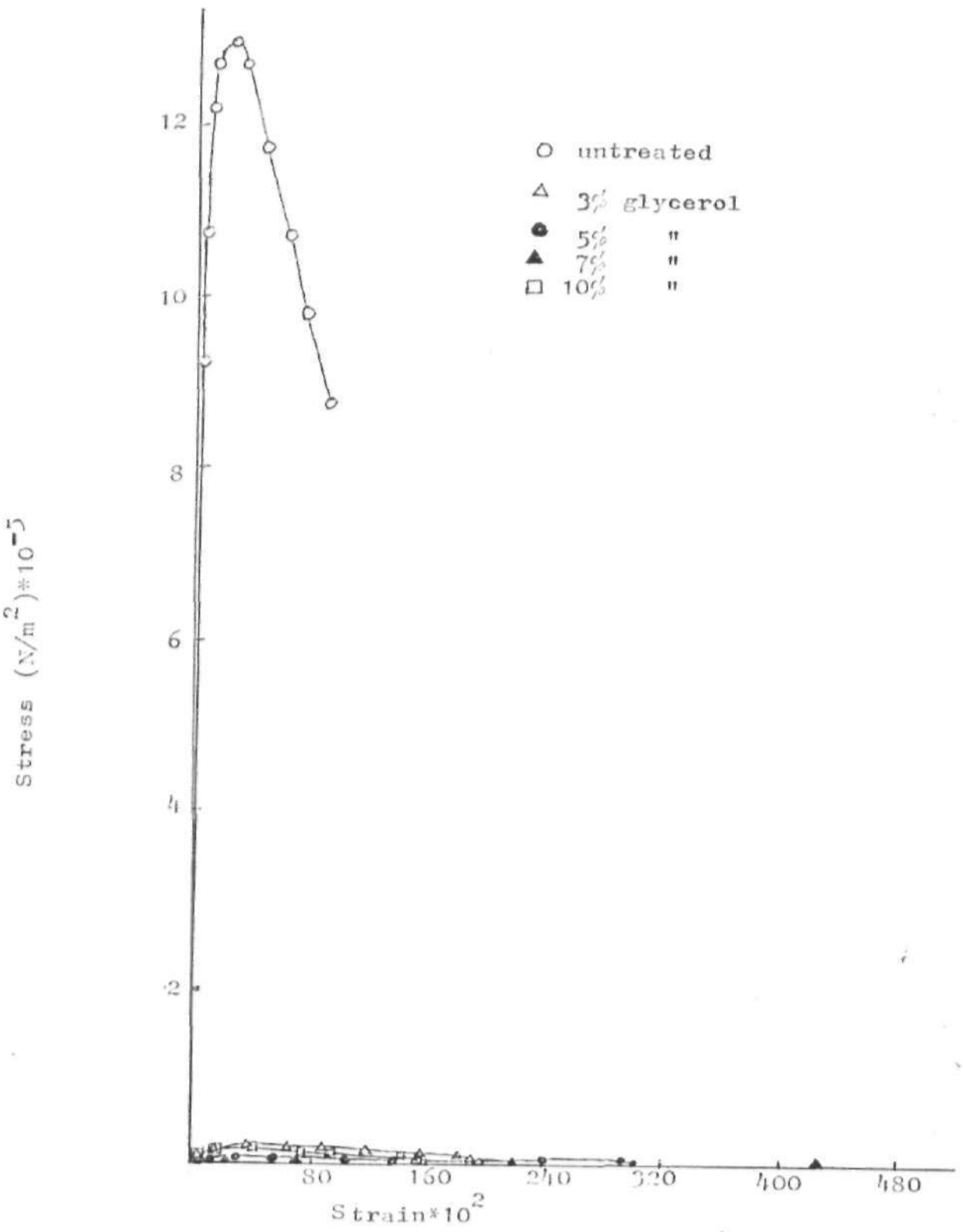


Fig. APP4: Stress strain curves for glycerol plasticized gum arabic samples.

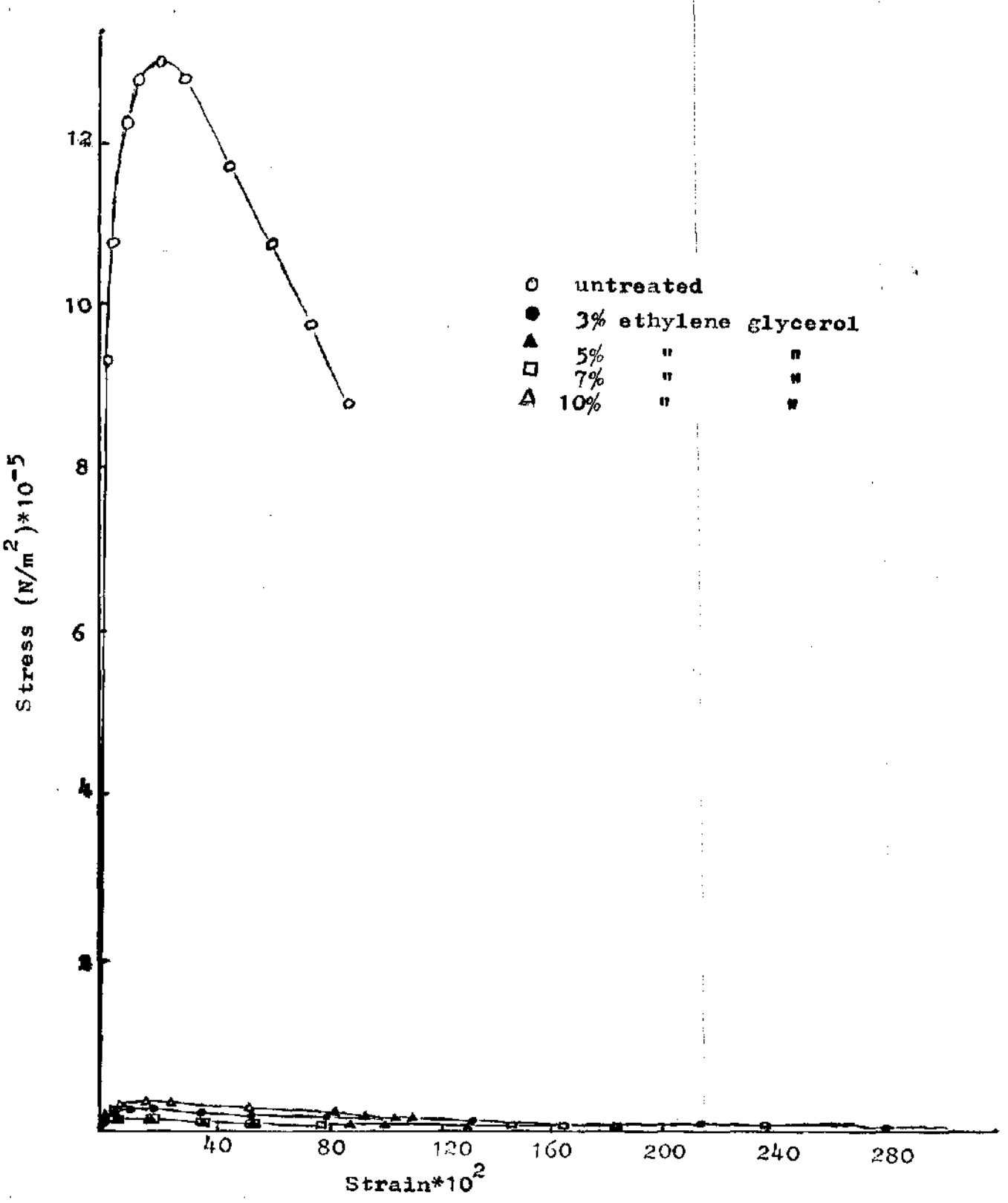


Fig. APP5: Stress strain curves for ethylene glycol plasticized gum arabic.

APPENDIX 2

Table AP2.1: Physical properties of Chemically modified gum arabic

Type of treatment	Weight % of additive	Modulus of rigidity $(N/m^2)*10^{-6}$	Ultimate tensile stress $(N/m^2)*10^{-5}$	Strain at break
Acetolysis	3	46.02	8.50	.96
	5	32.40	7.70	1.07
	7	28.54	7.01	1.33
	10	5.79	2.70	1.94
Treatment with	3	39.15	6.77	1.26
acetic anhydride	5	22.80	3.36	.97
	7	24.17	5.90	1.02
	10	20.31	4.73	1.17

Table AP2.2: Physical properties of physically modified gum arabic

Type of plasticizer	Weight % of additive	Modulus of rigidity $(N/m^2)*10^{-6}$	Ultimate tensile stress $(N/m^2)*10^{-5}$	Strain at break
Sorbitol	3	.40	.30	4.27
	5	7.03	1.78	*
	7	2.97	1.05	*
	10	.29	.12	5.03
Glycerol	3	.51	.22	1.96
	5	.29	.10	3.12
	7	.06	.03	*
	10	.55	.21	1.73
Ethylene glycol	3	.48	.20	3.48
	5	.33	.09	2.89
	7	.12	.09	1.73
	10	.83	.28	1.08

APPENDIX

The computational procedure for the caliberation curve of Figure 3.1 is presented here.

The weight of dry gum arabic including dirts and tree barks, dissolved in water was 6.39kg. While the weight of dirts removed was 0.57kg. the weight oof dry gum arabic left in the solution is therefore 5.82kg. The weight of the solution after removal of dirts was 17.865kg. The concentration of gum arabic in the solution in weight percent is therefore given as

$$c_{g.a} = \frac{5.82}{17.865} * 100 = 32.58 \text{ wt\%}$$

The amount of gum arabic present in 500g of stock = 0.3258 * 500 = 162.9

During concentration of gum arabic it is assumed that only water is given off and therefore the amount of gum arabic in the solution remains unchanged. If 500g of stock is therefore concentrated, the equation of the curve relating weight of the stock, as concentration progresses, to the concentration of gum arabic is given as

$$y = \frac{162.9}{x} * 100$$

where y = concentration of gum arabic in weight percent

x = weight of stock as concentration progresses.

It should be noted that starting the concentration of stock with weights other 500g renders the caliberation curve equation invalid.

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