Quality Assessment of the Physico-Mechanical and Elemental Composition of Three Pencil Grades and Eraser Types Produced in Nigeria

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ABSTRACT: The quality assessment of the physical (pH, electrical conductivity, density, writeability, eraseability), mechanical (compression test and break strength) and elemental composition of the pencil grades HB, 2B and 3B and eraser types of brand names Ben 10, Tiky 20 and the commonest White eraser in Nigerian primary school (Gummes Co. China) was carried out. The diameter of the graphite part increased in the order HB < 3B < 2B. The pH range of the pencil types was 7.0 – 7.4. 2B pencil exhibited the best writeability quality followed by 3B pencil. The compression qualities of the three pencil types were not statistically different ($P < 0.01$). 3B pencil is the strongest of the pencil types studied, while HB has the least break strength. Cr level by atomic absorption spectrophotometry was lowest in 3B pencil (1.541 µg/g) and highest in 2B (3.700 µg/g). Level of Pb was higher in 2B and HB (4.688 µg/g), while Cd was highest in HB (1.633 µg/g). Fast neutron activation technique indicated that Fe and Zn were elevated compared to the levels of Cr, Cd and Pb in the pencils. The pH range of the eraser brands was 6.2 – 7.3. The best eraseability quality was in Tiky 20 and the worst in Ben 10 eraser. The eraser brands contain some heavy metals in the order Pb > Cr > Cd. Though, the levels of the trace metals and essential elements detected in the school items are below the recommended limits, regulatory measures should be directed towards maintaining the standards of school items.

KEYWORDS: Quality assessment; Mechanical properties, Elemental composition, Pencil grades, Eraser

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I. INTRODUCTION

Ann (2009) assessed the health implications of relevant chemical substances in school bags, toy bags, pencil cases, pencils, chalk and eraser to consumers, primarily children in Michigan, United States. Learning in schools at the primary level from the beginning of the 1980s and lately in the pre-primary level does commence with the use of pencil and eraser. From this tender age, pupils are subjected to dermal exposure, ingestion and inhalation of these school items, and a plethora of others. Health risk may be posed over time since children absorb relatively more materials through their intestines than do adults (Cobb and Lippincott, 1981).

A pencil is usually made up of a piece of graphite mixed with a clay binder, leaving grey or black marks that can be easily erased; this core is encased with a cylinder wood. The case prevents the core from breaking, and also from marking the user's hand during use. The writing or drawing is durable, resistance to moisture, most chemicals, ultraviolet radiation and natural aging. Other types of pencil core, though less widely used are charcoal pencils, coloured pencils, grease pencils and so on (Petroski, 1989). A wide range of grades is available of which the most useful, from softest to hardest are: 6B, 4B, 2B, HB, F, H, 2H, 4H and 6H (Sheila, 1984).

Typical erasers are made from synthetic rubber (commonly styrene and butadiene), but more expensive or specialized erasers are vinyl, plastic or gum-like materials. For the improvement of an eraser quality, several softeners such as animal or unsaturated vegetable oils mixed with sulphur are added to natural rubber (Sami, 2002). Whiteness in eraser is produced by adding zinc oxide and titanium oxide; redness by iron oxide and other colours with the addition of various organic dyes (Rose, 1997). Erasers pick up graphite particles from the surface of paper; since the molecules of erasers are adhering than the paper. The eraseability tendency and the amount of eraser crumb left on the paper surface are some indices that signal the quality of pencil and eraser.

Children are far more susceptible to toxic metals poisoning through pica activities (Mielke et al., 2005; Ekwumemgbo and Omoniyi, 2013), use of toys, ingestion of school items like pencil, eraser, crayon and so on. Metals that are most often implicated for human poisoning are copper, nickel, cadmium, chromium, arsenic, lead and mercury; these have also been linked to damaged or reduced mental and central nervous function, damage to blood composition, lungs, kidneys, liver and death (Castañeda et al., 2012, Health Canada, 2007).

This work investigates the quality of three pencil grades HB, 2B and 3B (Star brand) and those of three eraser types of brand names Ben 10, Tiky 20 and the commonest white eraser in primary school produced by Gummes Co. China. The physical properties (pH, electrical conductivity, density, writeability/eraseability); mechanical properties (compression test, break strength) and elemental composition (using absorption spectroscopy and neutron activation techniques) of the pencils and erasers were carried out using standard methods; this was triggered by the evident indication that there is dearth of information concerning the standards of these school items in Nigeria.

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The findings of this work would be relevant in ascertaining the level in which the school items meet the regulatory standards, and to ensure that they do not tend to pose health risk to pupils on the long run.

II. MATERIALS AND METHOD

A. Sample Collection

Pencil grades HB, 2B and 3B and eraser types of brand names Ben 10, Tiky 20 and the commonest white eraser in primary school (Gummes Co. China) were purchased from Zaria market in Kaduna State, Nigeria in July 2012. The weight for each pencil grade with its attached eraser was determined using an analytical balance (H15, E. Mettler Co., Switzerland, accuracy 10^{-4} g), after which the eraser was removed and the weight of the wooden pencil part, likewise that of the graphite components of each sample separately determined. The weight of each of the eraser brands was also determined.

The bulk density of each of the pencil types and eraser brands was then determined as weight per unit volume of sample. A 1.3 g amount of each of the graphite part of each pencil grade was ground in an agate mortar and pestle, 20 ml of distilled water was added to the ground graphite and the pH and electrical conductivity determined accordingly (Maclean, 1982). This procedure was also carried out on 1.8 g of each eraser brand.

Writeability test was carried out by having 100 cubes of 1 cm x 1 cm x 1 cm being drawn on the pages of a notebook using HB, 2B or 3B pencil. Each of the pencils with the length of the graphite part being 0.10 mm was used to shade the cubes with the application of equal force and positioning the pencil at approximately 45^{o} as much as possible, by the use of a pencil hardness gage that is composed of eight mechanical drawing lead holders, each pencil graphite was mounted in a circular array on a plastic cylinder at the Laboratory of Strength of Materials Department of Mechanical Engineering, Ahmadu Bello University, Zaria (ASTM D3363). Then the number of boxes shaded by equal amount of each of the pencil type was counted after the shading.

Eraseability test of the different brands of erasers was conducted on 100 cubes of 3 cm x 3cm x 3cm being drawn on a notebook by using a HB pencil; the eraseability test was carried out by using the procedure presented by Tombow Pencil Co., Ltd., Japan (patent JIS S 6050) with modification. This was conducted by using each of the eraser brand of the same surface area (0.09 cm^2) to erase the 100 shaded boxes; and the number of boxes erased after were being counted. The amount of the eraser crumbs collected from each of the eraser brand were then weighed (Mac, 2000).

B. Determination of Some Mechanical Properties of the Pencil Types

The pencil samples were subjected to compression test using a universal material testing machine (HD96QD, Great Britain), at the Laboratory of Strength of Materials Department of Mechanical Engineering, Ahmadu Bello University, Zaria in April, 2013. As shown in Figure 1, the machine is made up of three compartments. Compression test was conducted on a specified dimension of the graphite part of each pencil type, by placing the graphite part between the plattern and the product label of the machine platform. As far as possible each of the pencil graphite type was centrally placed on the product label. Each graphite component of the pencil specimen of dimension 1.8 mm diameter and height 4.62 cm of HB, 2B or 3B pencil was placed on the hardened steel plate and load was gradually applied by a manually operated hydraulic press through an indenter or load applicator, until there was a sign of crack. At the point of crack, the load applied was noted on the load digital readout of the electrical box. The machine was set at a constant extension limit of 26.002 mm prior to exerting the load, and then the extension as a result of the applied load was obtained by the difference between the extension before and after the applied load. The test was conducted for both the vertical and horizontal positioning of the graphite components of each pencil type. The compression was calculated using the equation: $\delta C = W/A$; where W is the maximum load attained; A is the area of the load allocation.

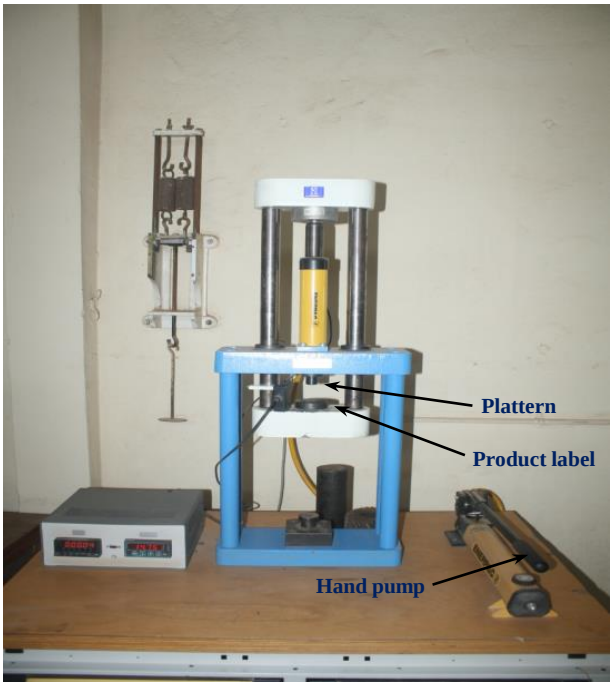


Figure 1: Universal material testing machine on a desk.

The universal material testing machine was used to determine the breaking load test, this was conducted by having a weight of 50 g tied to the centre of the graphite part of the pencil types HB, 2B or 3B (length 185 mm) supported on the ends of two cylindrical rods; then each of the sample was observed for about 5 minutes as additional load was gradually applied by a manually operated hydraulic press, within this period the load digital readout of the electrical box was read at the point when the applied load resulted to a breakage of the pencil graphite (ASTM D 2571). For each of the mechanical tests carried out on the pencil types n = 12.

C. Determination of Elemental Composition of the Pencil Types and Eraser Brands

The elemental level of Cd, Cr and Pb in the pencil and eraser samples was determined by using an atomic absorption spectrophotometer (model TAS990, Intec Co. Ltd., Rome) after acid digestion was carried out on 1.0 g of the sample using aqua regia. The quality assurance for the

analyses was conducted through the spiking method, to evaluate the sample digestion process and effectiveness of the atomic absorption spectrophotometer (Uwumarongie and Okieimen, 2008; Lori et al., 2009; Amit et al., 2010).

In addition, fast neutron activation analysis (FNAA) technique was utilized to determine the elemental composition of the items at the Experimental Nuclear Physics Department of the Centre for Energy Research and Training (CERT); using the D-T mode (mono energetic fast neutrons 14 Mev). Standard gamma sources of 22Na, 57Co, 133Ba, 137Cs and 152Eu were used for both energies according to Das et al. (1989) and Al-Mugrabi and Spirou (1987).

Statistical analysis was carried out to compare the properties studied in the different pencil types and the eraser brands using Pearson correlation at $P < 0.05$; and elemental compositions were compared by Students' t-test at $P < 0.05$.

III. RESULTS AND DISCUSSION

A. *Physical Properties of the Pencils Types*

The HB pencil without the attached eraser had a weight of 7 g, the 2B had a weight of 6 g while the 3B had a weight of 5 g. The graphite part of the HB, 2B and 3B each recorded a weight of 1.3389 g and height 185 mm. However, the diameter of the graphite part increased in the order HB < 3B < 2B. The bulk density of the HB pencil was 0.026 g/cm^3, this was closely followed by 0.020 g/cm^3 being for 3B and the density of the 2B graphite was 0.017 g/cm^3. These properties meet the applications of the pencils; as 2B and 3B are for artistic purposes and so requires less compact package of the graphite particles.

The pH of the pencil types follow the ranking 3B > 2B > HB. The pH was ranged 7.0 – 7.4. This is also within the standard for school items especially pre-nursery items (Mexico Ministry of Health, 2012). The HB pencil had mean electrical conductivity of 21.80 $\Omega^{-1}m^{-1}$ while 2B and 3B have 33.90 and 15.40 $\Omega^{-1}m^{-1}$ respectively. This signals the cationic and anionic compositions of the three pencil types (Gray, 2004).

The writeablity quality of the pencil types that was carried out by using a 0.1 mm length of each of the pencil types to shade cubes of 1 cm x 1 cm x 1 cm drawn on a white quality notebook indicated that, HB pencil shaded 63%, 2B pencil shaded 93% and 3B pencil of the same 0.1 mm length shaded 78% of the boxes. This result could be traced to the hardness of the pencil types, apart from this, the differences in the diameters of the pencil types which follow the ranking HB < 3B < 2B could partly account for the writeablity qualities. Though the darkest shade on the paper was by 3B, this was closely followed by 2B and the lightest was by HB (the hardest pencil type).

B. *Mechanical Properties of the Pencil Types*

From Table 1, an average of 0.03 kN was applied for a crack to be obtained on the graphite part of the HB pencil in the horizontal plane, the extension before the crack was 26.002 mm and the extension after the crack on the HB graphite sample was 25.896 mm giving a compression of 0.106 mm for the HB pencil in the horizontal plane, while a mean load 0.05 kN was needed for the same compression in the vertical plane. Also an average of 0.03 kN was needed for a 0.107 mm compression of the graphite part of 2B pencil in the horizontal plane, while 0.04 kN was needed for 0.106 mm compression in the vertical plane. Also 3B pencil required an average of 0.04 kN for a 0.106 mm compression of the graphite part in the horizontal plane, while 0.05 kN was needed for the same compression in the vertical plane. The compression qualities of the three pencil types were not statistically different ($P < 0.01$).

Table 1: Compression test on HB, 2B and 3B pencils.

Pencil Type	Mean Load (kN)	Extension before Crack (mm)	Extension after Crack (mm)	Position
HB	0.03	26.002	26.896	Horizontal
	0.05	26.002	26.896	Vertical
2B	0.03	26.001	26.894	Horizontal
	0.04	26.001	26.895	Vertical
3B	0.04	26.001	26.895	Horizontal
	0.05	26.001	26.895	Vertical

The result of the breaking load test indicated that the graphite part of 3B pencil is the strongest of the pencil types studied; this could hold the 50 g load beyond 5 min with no sign of breaking. The 2B specimen was bent but did not break at 5 min loading time. However, the graphite component of HB broke immediately the load was attached. This denotes that HB pencil commonly used by pupils has the least breaking load; and so should be cautiously utilized to minimize breakage. So, the lower the compressibility property of the pencil sample, the lower the breaking load, and subsequently the larger its hardness.

C. *Elemental Composition of the Pencil Types*

Data was analyzed using statistical analysis software (SAS), and a one-way ANOVA of students' t- test employed to assess differences in the mean values of the metal ions due to difference in type of the school item at $P < 0.05$. The quality assurance carried out through the spiking method revealed that the mean % recovery for the analyses ranged from 82.9 ± 0.15 to 93.3 ± 0.40 mg/kg.

Following from Figure 2, the mean level of chromium ion was lowest in 3B pencil (1.541 µg/g) and highest in 2B pencil (3.700 µg/g). Pb level was also lower in 3B pencil brand (3.750 µg/g) than in 2B and HB pencil brands (4.688 µg/g). The AAS result also indicated that the level of Cd ion was lower in 3B and 2B pencils (0.900 µg/g) than in HB pencil (1.633 µg/g). This implies that the levels of these metals follow the trend Pb > Cr > Cd. Though, these levels are below the threshold permits of elements in school supplies for pre-nursery pupils as recommended by Ministry of Health Mexican Official Standard, Cr is 25 µg/g, Cd 50 µg/g and Pb 90 µg/g (Mexico Ministry of Health, 2012).

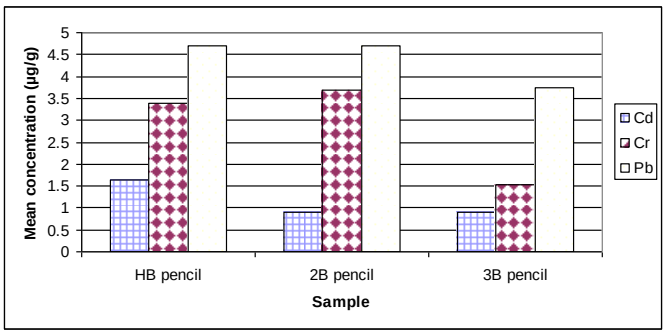


Figure 2: Distribution of cadmium, chromium and lead in the pencil types from AAS.

The results shown in Table 2 for the fast neutron activation technique indicated that Fe was highest in HB pencil (297.5 ± 167.6 µg/g) and least in 3B pencil (133.0 ± 98.6 µg/g); these values recorded statistical significance at $P < 0.05$. Ni was highest in HB pencil (14.6 ± 6.3 µg/g); while Pb was highest in 2B pencil (13.10 ± 6.1 µg/g); Zn level was highest in 3B pencil (111.9 ± 49.6 µg/g); on the other hand the concentration of Cr was highest in 3B pencil (41.5 ± 12.7 µg/g) and Cd recorded the highest level in 2B pencil (1.3 ± 0.7 µg/g). Students' t-test showed no significant difference in the levels of these metals in the pencil types studied. The essential elements detected, such as Fe and Zn were elevated compared to the levels of the heavy metals in the school item. Though, the recorded levels of the heavy metals in the pencil types were generally higher using neutron activation analysis (NAA) than the atomic absorption spectroscopy (AAS) values presented in Figure 1; Cd concentrations in the pencil types compare relatively close using NAA and AAS techniques. However, the levels of Pb in the pencil types using NAA technique were generally about three-fold the result from AAS; while the levels of Cr in the pencils using NAA were generally about ten-fold the result obtained from AAS. The variance in the results from the two techniques is due to the higher degree of accuracy and precision of atomic absorption spectrophotometer.

From the results, the highest levels of potentially harmful metals measured in the pencil types are within the recommended tolerable limits in school items; Ministry of Health Mexican Official Standard recommended Cr to be 25 µg/g, Cd 50 µg/g and Pb 90 µg/g. The results of neutron activation analysis on the pencil samples had uncertainty of the calculated values to be 10 – 17%.

Table 2: Elemental compositions of pencils utilising neutron activation analysis.

Metal	Concentration (µg/g)		
	2B pencil	3B pencil	HB pencil
Fe	195.3 ± 111.9	133.0 ± 98.6	297.5 ± 167.6
Ni	9.2 ± 4.1	13.4 ± 5.8	14.6 ± 6.3
Pb	13.1 ± 6.10	12.92 ± 4.04	10.55 ± 6.75
Zn	94.4 ± 27.6	111.9 ± 49.6	94.9 ± 38.5
Cr	37.8 ± 4.1	41.5 ± 12.7	31.8 ± 11.2
Cd	1.3 ± 0.7	0.8 ± 0.2	1.1 ± 0.6

D. Physical Properties of the Erasers Brands

The weights of the erasers are: White eraser (Gummes Co. China) 2.36 g, Ben 10 eraser 1.18 g and Tikky 20 has a weight of 4.72 g. White eraser has surface area of 18.4 cm^2, Ben 10 has surface area of 6.22 cm^2 and Tikky 20 has surface area of 24.34 cm^2. The pH of White eraser was 6.2, Ben 10 eraser 6.98 and Tikky 20 had pH 7.3. These values are within the standard for school items especially pre-nursery items (Mexico's Ministry of Health, 2012). The mean electrical conductivity measured for White eraser was 5.2 $\Omega^{-1}m^{-1}$, Ben 10 eraser 3.6 $\Omega^{-1}m^{-1}$ and Tikky 20 Eraser 9.2 $\Omega^{-1}m^{-1}$.

Eraseability test result of the erasers of different brands on 100 cubes (3 cm x 3 cm x 3 cm) of HB pencil shades on a notebook revealed that the weight of the eraser crumbs obtained after the eraseability for White eraser was 0.15 g, Ben 10 eraser 0.33 g and Tikky 20 eraser 0.08 g. This indicates excellent eraseability for Tikky 20 and poor for Ben 10 eraser. The amount of residues from erasers to classroom dust is of health concern. Ekwumemgbo and Omoniyi (2013) reported that primary school soil-dust of the six geopolitical zones in Nigeria contained high Pb levels; the highest being at the North-east (131.60 ± 70.98 mg/kg) in the dry season.

By using White eraser brand for erasing the shaded cubes drawn by each of the three pencil types, it was visualized that the shades by HB was cleaned neatly, the shades by 2B was cleaned with faints of black colour left, while the shades by 3B was cleaned with difficulties and patches of black colour left. This is not unconnected with the hardness of the pencil types being in the order HB > 2B > 3B.

E. Elemental Composition of the Eraser Brands

Neutron activation technique indicated mean concentration of carbon to be 18.90 wt% in Ben 10 eraser, 19.05 wt% in White eraser and 19.65 wt% in Tiky 20 eraser. Sulphur level was 17.60 wt% in Ben 10 eraser, 10.26 wt% in White eraser and 17.00 wt% in Tiky 20 eraser. There was no significant difference in the level of C and S in the three brands of eraser (students' t-test, $P < 0.05$). The organic source of rubber and vulcanization process it undergoes explains the presence of C and S in the item.

The result of elemental composition of the eraser brands from atomic absorption spectrophotometry presented in Figure 3 indicated that the concentration of Pb was highest in all the eraser types followed by Cr and the least was Cd. However, White eraser had the highest concentration of Pb (5.625 µg/g) and the least was in Ben 10 eraser (2.825 µg/g). Tiky 20 eraser had the highest Cr level (2.775 µg/g) and the least was in White eraser and Ben 10 eraser (1.541 µg/g). The highest level of Cd ion was recorded in White eraser (1.633 µg/g) and the least in Ben 10 and Tiky 20 eraser (0.900 µg/g). The level of Pb in Ben 10 eraser was significantly lowered compared to the two other eraser brands ($P < 0.05$). The recorded amounts of the metals in the eraser brands are below the threshold permits in school items for pre-nursery pupils; following the Ministry of Health Mexican Official Standard, Cr is 25 µg/g, Cd 50 µg/g and Pb 90 µg/g (Mexico Ministry of Health, 2012); and far below the limits of Cr being 60 µg/g, Cd 75 µg/g and Pb 90 µg/g recommended by South African National Standard (SANS, 2006).

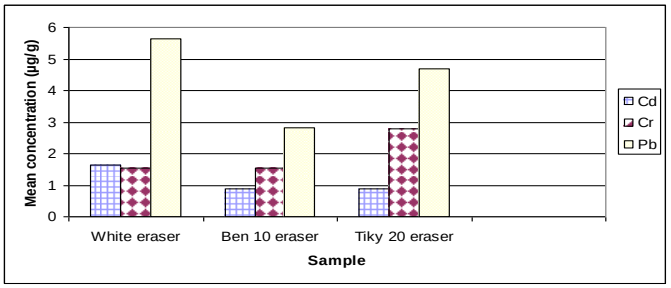


Figure 3: Distribution of cadmium, chromium and lead in the eraser brands from AAS.

IV. CONCLUSION

The quality assessment tests lead to the findings that 2B pencil has the best writeability quality closely followed by

3B and the least was in HB. The compression qualities of the three pencil types are not different ($P < 0.01$). Graphite part of 3B pencil is the strongest of the pencil types studied. Atomic absorption spectrophotometry indicated trace levels of Cr, Pb and Cd in the pencils and erasers with the levels being lower than the permissible amounts in school items. But the essential elements detected in the pencils were in elevated amounts compared to the levels of heavy metals. The heavy metals in the pencils follow the ranking Pb > Cr > Cd. Tikky 20 eraser has excellent eraseability quality followed by White eraser and the least was Ben 10 eraser. The physico-mechanical properties of the items should meet standards to satisfy service for money paid. Though, the levels of potentially toxic metals in the pencil types and eraser brands are low, attention of regulatory bodies should be concerted towards ensuring standards of these items; since nursery pupils are daily subjected to the tendency of ingesting these school items.

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