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Design and Production of Combat Boot Soles for Military Applications

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ABSTRACT*: The effect of carbonized palm kernel shell powder as filler for improvement of the performance of Natural rubber for production of Military Boot Soles has been studied and documented here. The palm kernel shell powder was carbonized at temperature of 400 degree centigrade for twenty four hours in a furnace and ball milled to a particle size of 100µm. The carbonized palm kernel shell powder was characterized to determine the ash content, moisture content and density in the lab. It was filled with hundred grams (100g) of natural rubber and other compounding ingredients, it was then roll milled using Allen-Bradley Laboratory Scale Two-Roll Mill (802T-WS1P). The mechanical, physical, chemical and tribological properties of the vulcanizates were investigated. The sample filled with 30g of filler exhibited the highest hardness value of 64.6 shore A, whereas sample with 20g filler loading exhibited lowest hardness, best abrasion resistance was obtained for the same sample with 0.59 % weight loss. The results also show that sample with 30g filler loading gives the optimum tensile strength of 69.25N/mm², the physical test also revealed that the samples exhibit better resistance to solvents such as water, petrol and diesel as the filler loading increases. The samples filled with 45g filler loading had the best resistance to attack by diesel and petrol. A combat boot sole was produced with the formulation of vulcanizate with 20g filler having the best mechanical, physical and tribological properties using a Carver Inc. Hydraulic Hot Press (3851-0) after compression of the composite fed into an aluminiummould for 30minutes. The physical properties (weights) of each pair of sole samples studied were compared with that of the combat boot sole prototype produced, and the results showed that the foreign sole produced with EVA weighed 638g. The NDA Cadets boot sole weighed 754g and the military boot sole procured from the commercial market weighed 756g whereas the prototype sole produced in this research work weighed 488g.*

KEYWORDS: *Combat Boot Sole, Natural Rubber, Palm Kernel Shell powder, Carbonized Palm Kernel Shell powder, Aluminium,Mould.*

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I. INTRODUCTION

Combat boots are military boots designed to be worn by soldiers during combat operations, training, parades and other ceremonial duties. Modern combat boots are designed to provide a combination of grip, ankle stability, and foot protection suitable for a rugged environment [1]. They are traditionally made of hardened and sometimes waterproofed leather. Today, many combat boots incorporate technologies originating from civilian hiking boots, with nylon side panels, which improve ventilation and comfort to the users. They are also often made specially for certain climates and conditions, such as jungle boots, desert boots, and cold weather boots as well as specific uses, such as tanker boots and jump boots [1].

In the military, it is one of the essential soldiers' equipment, hence it constitutes the most widely issued footwear in the Nigerian Defence Academy (NDA), Kaduna, Nigerian Army Depot, Zaria and other Military and Paramilitary Institutions in Nigeria. Cadets, Recruits and Prospective Officers receive these boots at the commencement of their basic military training and special courses and use it for almost all activities that comprises "boot camp". An extensive volume of research have been carried out to identify common types of injury and their related risk factor. A number of preventive strategies have been developed within military bodies around the world to address these issues. The relative success of these strategies is highly variable; however, with advancement in technology and more research work, new approaches will become more available and existing strategies may become more effective.Cadets, Soldiers and Military Staff carryout majority of their activities in uniform which includes the combat boot as footwear. These activities which consist of walking, running and climbing in both plain and rugged environments make the boot uncomfortable and mostly leads to injuries [2].

Military personnel serve in many capacities around the world and there are two factors of paramount importance to all efforts; Soldiers should be physically capable for duty and that they should return safely. The most prevalent factor that could prevent the achievement of these two criteria is musculoskeletal injury. Soldiers injured in basic training maybe unable to deploy, while others injured during deployment may not be fit to return to active duty [3].

Furthermore, once a musculoskeletal injury is incurred, the risk of sustaining another such injury increases causing a greater risk of attrition [4]. From the data of NDA cadets, Military and Para-Military personnel interviewed on the subject results indicated that about 70% of them had some unpleasant experience on issues related to combat boot use and associated injuries. Foot and lower limb injuries affects the combat readiness of any soldier. Hence it becomes very significant to think through the degrees at which injuries can arise and in what situation.

This work designed and produced combat boot soles for military applications aimed at reducing the injury outcome amongst military population by considering weight reduction in the combat boot sole and improving its ability to absorb shock and become more comfortable during usage by military and para-military personnel. The compression moulding technique was employed for the production of a light weight durable rubber composite sole using natural rubber, palm kernel shell and other additives.

II. REVIEW OF RELATED WORK

Simpson et al 2018, studied the role of Footwear and workload on the ground reaction forces during a simulated ankle sprain Mechanism. It was stated that ankle sprains are common lower limb injuries amongst military personnel, which may be likened to the nature of their work and footwear. It was discovered that a lot of work have been done on modifying existing designs of military combat boots, but their influence on ground reaction force (GRF) attenuation capabilities during an ankle perturbation are unknown.Therefore there study was aimed at examining the potential differences in GRFs during an ankle inversion perturbation in a standard issue (STN) and minimalist military boot (MIN) before and after a simulated military workload [5].

Riddiford-Harland et al 2017 research, noted that work boot design affects the way workers walk. They discovered that safety boots are compulsory in many occupations to protect the feet of workers from undesirable external stimuli, particularly in harsh work environments. Unfortunately, they are often designed more for occupational safety at the expense of functionality and comfort of the wearer [6].

Miguel D and Faustino S (2016) in their work, "a new methodology approach for shoe sole design and validation", showed thatshoe soles are extremely complex to design and produce due to their organically shaped but technically precise nature and their production constraints. Consequently, they noted that there is a need for the increased design process flexibility offered by the use of specific Computer Aided Design (CAD) methodologies and techniques, to facilitate the work of expert designers and permit effective construction of the three-dimensional elements comprising the complete structure [7].

Jos Van D (2014) noted in "Common Military Task-Marching", military load carriage capacities and effects of load borne by soldiers to soldiers' mobility and the foot. He described foot marches as the movements of military troops and equipment mainly by foot with limited support by vehicles. And stated that combat loads consists of three categories: Fighting Load (limit 21.7 kg), Approach March Load and Emergency Approach March Load (limit 32.7 kg). An additional guidance states that a soldier's weight must be taken into account. Hence optimal load for a soldier has been determined to be 20 to 30 percent of their body weight for combat missions. The maximum load should not exceed 45 percent of the soldier's body weight for sustained non-contact movements [8].

Carolyn K (2013) studied the effects of four different sole designs for military boots on the incidence of lower extremity overuse injuries among men and women undergoing U.S. Army basic combat training. The boot uppers issued to the trainees were identical, but the soling design incorporated different raw material composition and construction technique [9].

Mohammed et al (2012) analyzed shoe manufacturing factory by simulation of production process. After the analysis of various shoe production processes, they developed a specific production policy for shoe making. Also, a simulation study was developed to see at what degree the variations of the models effect the throughput rate [10].

Chladek J (2002) in his work on mine resistance boot, noted that each war brings killing. To defeat the enemy, machine guns, cannons, ranks and also landmines can be used [11]. The work which began in 1997 was geared at solving the problem of foot protection. First, the researcher collected different materials appropriate for amour construction and then prepared a number of different flexible armours. The armours differed in material, number and thickness of layers, and technology of layer connection. Each sample was then rested by explosion. After successful trials with different explosive charges, there appeared a clear request: co-operation with a boot producer is necessary. Subsequently, representatives of Zeman Shoe Limited met with Dr. Chladek, an independent expert in explosives, during an exhibition in 1999 (ID ET 99) and a new era in R & D of blast protective boots successfully began [11]. They produced a special all-leather boot with protection against explosion of AP contact mines and related UXO items with a charge around 50g of high explosive. The boots can be provided with Sympatex lining, which ensures I00 percent waterproof protection while keeping comfort by letting perspiration out of the boot. The Mine resistant (Blast Protective) boot model offers some levels of protection, which includes; Multi-Layer Armour in Sole, Inner Armour, Ballistic Protection, Anti Perforation Protection and Tread.

Dyck W (1992) in his review on footwear for military in cold and wet scenarios, revealed that proper footwear for the military has been a subject of concern for a very long period of time. Although there have been many advances in the footwear industries in recent times with respect to new materials, new designs, and new production processes, it was noted that the perfect boot for many scenarios is still not available. The boot itself should not form a potential cause of injury due to its construction. Seams, rivets, nails etc. obviously should not protrude [12].

Joseph H and Carolyn K (1992) work on Biomechanical Analysis of Footwear, studied a two-phase analysis of footwear military boots and commercially available footwear. They were subjected to materials tests that included measures of impact, flexibility, stability, resistance of the outsole to accelerated wear, water penetration during immersion, and static and dynamic friction of the outsole. The military boots were the black leather combat boot and the hot weather jungle boot [13]. The commercial foot wears were: a running shoe, a cross trainer, a work boot, a basketball shoe, a hiking boot, and a walking shoe. These items were not developed for use as military field footwear, but they incorporate materials and design concepts that could be adapted to a military boot. All footwear types were analyzed unworn and after having been worn for over 300 hours. The results indicated that the commercial running shoe and the cross trainer had impact properties superior to all other items. The running shoe was also the most flexible and took longest to reach the criterion of accelerated wear. The jungle boot showed good medial and lateral stability and the combat boot had good resistance to water penetration. The military and the commercial footwear had comparable coefficients of friction [13].

Alice F and Douglas S (1967) modified a method of footwear construction known as Direct Molded Sole (DMS) for the US Army's tropical and all-leather combat boots. The work was carried out at The U.S. Army Natick Laboratories (NLABS), the researchers developed the special component materials, boot designs and fabrication techniques required to produce military footwear by the DMS process [14]. The sole and heel of the DMS boots are moulded directly to the boot uppers on high-pressure vulcanizing machines, eliminating the sole stitching and heel nailing which were the major points of failure in welt combat footwear. The DMS boots are significantly more durable and more comfortable than welt construction boots, and will save the military money both in production cost and by reducing boot repair and maintenance problems. The DMS process has enabled NLABS to incorporate special protective features into the tropical combat boot, including a steel innersole to resist penetration of the boot bottom by punji stakes, and a wedge shank to deflect and absorb the impulse of antipersonnel land mines [15].

2.1 Factors Responsible for Injuries

i. Training

One aspect of military life that has a significant impact on injuries is the training that personnel must undergo. All recruits typically need to complete some level of physical training or basic combat training before progressing to unit or division's specific training programs.It is important that soldiers train, improve and maintain a certain level of physical capacity for any tasks they may need to perform. Some training principles that have been identified are specificity, recovery and progressive overload. Training needs to stress the body sufficiently to elicit a training response; however; with increased intensity, there is also an increased risk of injury [16].

ii. Load Carriage

Weight-bearing activities have been reported as a potential cause for injury amongst military populations. This is largely attributable to the amount of equipment and body armour that soldiers carry, whether in training or during operations. In the US Army Field Manual, combat load is divided into three categories; fighting load (FL), approach march load (AML) and emergency approach march load (EAML) [17].

(a) Fighting Load

The fighting load includes bayonet, weapon, clothing, helmet, load bearing equipment and a reduced amount of ammunition. For hand-to-hand combat and operations requiring stealth, carrying any load is a disadvantage. Soldiers designated for any mission should carry no more than the weapons and ammunition required to achieve their tasks; loads carried by assaulting troops should be the minimum. Unless some form of combat load handling equipment is available, cross-loading machine gun ammunition, mortar rounds, antitank weapons, and radio operators equipment causes assault loads to be more than the **limit of 21.7 kg**. This weight restricts an individual's ability to move in dynamic operations. Extremely heavy Fighting Loads must be rearranged so that the excess weight can be redistributed to supporting weapons or can be shed by assaulting troops before contact with the enemy [18].

(b) Approach March Load

The approach march load includes clothing, weapon, basic load of ammunition, load bearing equipment, small assault pack, or lightly a loaded rucksack or poncho roll. On prolonged dynamic operations, the Soldier must carry enough equipment and ammunitions for fighting and existing until re-supply. In offensive operations, Soldiers designated as assault troops need equipment to survive during the consolidating phase, in addition to carrying munitions for the assault. A **limit of 32.7 kg** (FM 21-18)for a Soldier should be enforced [17].

(c) Emergency Approach March Loads

Circumstances could require Soldiers to carry loads **heavier than 32.7 kg** such as approach marches through terrain impassable to vehicles or where ground/air transportation resources are not available.Therefore, larger rucksacks must be carried. The Emergency Approach March Loads can be carried easily by well-conditioned Soldiers. When the mission demands that Soldiers be employed as porters, loads of up to 54.5 kg can be carried for several days over distances of 20 km a day (FM 21-18). Although loads of up to 68 kg are feasible, the Soldier could become fatigued or even injured. If possible, contact with the enemy should be avoided since march speeds will be slow [19].

The Infantry school added to this guidance that a soldier's weight must be taken into account. The **optimal load for a soldier has been determined to be 30 percent of his body weight,** and the maximum load should not exceed 45 percent of his body weight [20].

Injuries associated with load carriage are **foot blisters**, **lower back pain**, **metatarsalgia**, **stress fractures**, **knee pain**, **rucksack palsy**, **sensory neuropathies** and **local discomfort**. A large proportion of these injuries are due to the increase in load due to the soldiers pack and equipment. For example, foot blisters are common due to the increase in pressure on the plantar surface of the foot and braking forces during locomotion. Similarly, lower back pain, metatarsalgia, stress fractures and knee pain are due to increases in load and the kinematic adjustments to compensate for it. Rucksack palsy is a traction injury of the upper brachial plexus that is caused by pressure from the shoulder straps. This condition can cause numbness, paralysis, cramping and minor pain in the shoulder girdle, elbow flexors and wrist extensors, which can severely limit soldier functionality. Excessive load and incorrectly adjusted shoulder straps have been cited as potential causative factors for rucksack palsy. Hip belts are used to alleviate this by distributing load from the shoulders to the hips [17, 18].

iii. Footwear

One of the most important influences on injury mechanics and kinematics of the lower limb is footwear. Of particular interest is the effect footwear can have on gait as any change in gait pattern from what the body is accustomed to is associated with an increased risk of injury. Military footwear, such as combat boots are designed to protect the foot, attenuate shock at foot strike and control medio-lateral foot motion. Military footwear, however, has a number of design properties that may result in undesirable effects.

The property with the most obvious effect is the mass of the boots. By wearing boots, the effective mass of the foot is increased, thereby increasing the rotational inertia of the leg. This increases the muscle load, energetic cost of locomotion and rate of fatigue and hence increases the risk of injury [20]. The increase in energetic cost for carrying loads on the feet has been found to be four times more costly than walking without load. Footwear can also have a significant influence on gait by restricting motion of the foot. This restriction can result in increased loading at the ankle, knee and hip as well as decreased energy absorption during certain parts of the stance phase. This can in turn result in compensatory gait changes. Restriction of the ankle is associated with an increase in energetic cost and is a function of the design of the boot shaft, which provides the primary support in this region. The shaft has two competing design constraints; it must be rigid to support the joint, whilst being flexible enough to allow a sufficient range of motion to achieve efficient locomotion [21].

Even a small change in ankle dorsiflexion can have a significant effect on Achilles tendon strain and hence injury. Ankle sprains have been identified as the most common injury, suggesting that current boot shaft design and the running shoes used during physical training may provide inadequate support to the ankle. Unfortunately, specific details regarding the type of sprain and method of injury are not available, and combat boot and running shoes usage during physical training varies between countries and services, so insufficiencies in design cannot be determined. A study by Bohm et al (2010) examining boot stiffness throughout the stance phase concluded that the primary effects of boot stiffness are limited to the ankle. This is however in contrast to other work suggesting sole stiffness plays a significant role at the metatarsophalangeal (MTP) joint. In contrast, studies have shown that footwear with cushioned heels may limit proprioception in the foot, thus compromising the ability of the body to adjust to the loads being applied. Smith et al (2003) has compared injury incidence when physical training is conducted in combat boots or in running shoes and they found no historical evidence to support an increase in injuries when wearing boots [22, 23].

III. MATERIALS, EQUIPMENT AND METHODS

3.1 Materials

The materials used for the production of the vulcanizates include; Dry Natural Rubber (NR), Benzothiazole disulfide (MBTS), Stearic Acid, Trimethyldihydroquinoline (TMQ), Zinc Oxide and Processing Oil supplied by the Department of Polymer Technology, NILEST Samaru-Zaria Kaduna State and Palm Kernel Seed Shells purchased from a commercial dealer at SabonGari Market, Zaria, Kaduna State,

3.2 Equipment

The equipment used for the production of the vulcanizates include; Weighing Balance (XPR4001S readability 0.1g, maximum capacity 4.1kg, Mettle Instruments Ltd, AE 200), MuverDurometer Hardness Tester (5019), Cole Parmer Hot Air Oven(60648), Hydraulic Hot Press(Carver Inc. 3851-0), Fortuna-Wepke Abrasion Tester(158/2FBM), Resilimpactor Testing Machine(412-07-15269C), ASTM-Standard Sieves(460), Laboratory Scale Two-Roll Mill (Allen-Bradley 802T-WS1P), Furnace (3420-RT2), Hounsfield Monsanto Tensometer (386083-W9) and Mekins Agro Products Milling Machine (N150). All the equipment are available at AhmaduBelloUniversity Zaria, Polymer and Textile Engineering labouratory and Nigeria Institute of Leather Science and Technology (NILEST) Physical testing labouratory.

3.3 Methods

3.3.1 Collection and Preparation of Palm Kernel Shells

Palm kernel Shells were sourced from within SabonGari Market, SabonGari Local Government Area of Kaduna State. The sourced palm kernel shells were sorted to remove foreign matters and washed with soap solution to remove stain. The washed palm kernel shells were sun dried for 48 hours. The shells were further dried in the hot air oven at temperature of 60 ^oC for 1 hour to reduce moisture. The palm kernel shells were then grounded into smaller particle size using Mekins Agro Products Ltd, Model No 150 grinding machine at the physical testing laboratory, NILEST, Zaria. The palm kernel shell was carbonized at a temperature of 350 ^oC for 30 minutes.

The palm Kernel Shell powder was further characterized to determine its Ash Content, Moisture Content and Density.

3.3.2 Characterization of the Carbonized Palm Kernel Shell Powder

(i) Determination of Moisture Content

The moisture content of the filler was determined by weighing 5 g of carbonized palm kernel shell powder in an evaporating disc. The weighed filler was place in the hot air oven at temperature of 120^oC for 30mins. The procedure was repeated until a constant weight was obtained. The moisture content was calculated using the equation below:

$$\%\ \text{Moisture Content} = \frac{Wo - W1}{Wo}\, x\ 100 \qquad (3.1)$$

Where,

Wo = Initial weight of the filler

W1 = Final weight of the filler at 120℃

(ii) Determination of Ash Content

The ash content of the filler was determined according to ASTM D297-35 by weighing 5 g of carbonized palm kernel shell powder in an evaporating disc. The weighed filler was placed in the furnace at temperature of 250^oC for 120 minutes. The samples was observed until it has completely turned ash. Ash content was calculated using the equation below:

$$\%\ \text{Ash Content} = \frac{Wo - W1}{Wo}\, x\ 100 \qquad (3.2)$$

Where,

Wo = Initial weight of the filler

W1= Final weight of the filler at 250℃

(iii) Density

It is also the mass in grams per unit volume of a substance. This is required for the determination of weight of the sole. It is defined mathematically as;

Density = mass/volume (g/cm³) (3.3)

The density of the filler was determined by weighing and recording the mass of 30 cm^3 beakers (W_1). The filler was filled in the beaker and the mass of the filler plus the mass of the beaker was determined (W_2). The density of the filler was calculated using the equation:

$$Density = \frac{W2 - W1}{30} \quad (3.4)$$

Where,

W_1 = Mass of beaker

W_2 = Mass of filler and beaker

3.3.3 Formulation and Compounding of the Natural Rubber Vulcanizates

Samples of the natural rubber vulcanizates filled carbonized palm kernel shell was prepared as shown in Table 3.1 below:

Table 3.1: Formulation of compounding Natural Rubber Vulcanizate

S/No	Additive	Control Sample	Other Samples								
		Sample A Quantity (g)	**B**	**C**	**D**	**E**	**F**	**D**	**H**	**I**	**J**
1	NR (g)	100	100	100	100	100	100	100	100	100	100
2	Zinc Oxide (g)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3	Stearic Acid (g)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
4	MBTS (g)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
5	TMQ (g)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6	Processing Oil (g)	10	10	10	10	10	10	10	10	10	10
7	Sulphur (g)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
8	Carbonized PKS (g)	0	5	10	15	20	25	30	35	40	45

Samples for testing were denoted A, B, C, D, E, F, G, H, I and J. Samples were compounded using a laboratory scale two-roll mill (Allen-Bradley, 802T-WS1P) at a temperature of 65°C for 5 minutes before sheeting out. The order of introduction of the ingredients for compounding is in accordance with table 3.1, with natural rubber first and sulphur being introduced last. The control sample is denoted 'A'. After compounding, cured samples for testing were prepared by putting sizeable quantities of the compounded ingredients into a metal mould of 100 mm x 100 mm x 3 mm and placed in hydraulic hot press at temperature of 120 ^oC and pressure of 3 bar for 30 mins for curing (vulcanization). The following Plates (1-7) show the raw materials used:

Plate 1: Natural Rubber (NR)

Plate 2: Zinc Oxide (Co-activator)

Plate 3: Stearic Acid (Co-activator)

Plate 4: MBTS (Accelerator)

Plate 5: TMQ (Antidegradan

Plate 6:Sulphur(Curing agent)

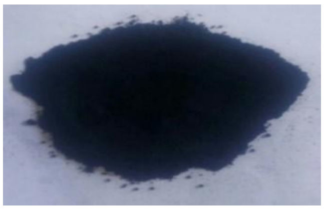

Plate 7:CPKSp (Filler)

3.4 Characterization of the Composites

The characterizations were carried out according to ASTM standards for testing materials.

3.4.1 Physical properties

(i) Solvents Absorption Test

The percentage solvent absorption of the composites is determined according to ASTM 2842 standard. The average percentage swelling rates of the produced carbonized palm kernel shell powder/natural rubber vulcanizates in water, diesel and petrol were determined using immersion and weight gain method at room temperature. Three different specimens of the vulcanized samples cut from 3 mm mould, weighed and then completely immersed in three air tight glass bottles containing the respective solvents and labeled accordingly. The samples were removed after 48 hours, dried with filter paper to remove excess solvent from the surface and reweighed immediately, this was repeated for seven days. The initial weight of the sample (w_1) and the final weight (w_2) were recorded.

The change in weight of the samples were determined and used to compute the percentage swelling of the samples using equation;

$$\% \text{ swelling} = \frac{W2-W1}{W1} x\ 100 \qquad (3.4)$$

Initial weight solvent absorption leads to the reduction of the fibre-matrix interfacial bond which consequently reduced the mechanical properties of the composite thereby reducing its lifespan. All polymeric materials will absorb moisture and other solvents to some extent which results in swelling and degradation which can cause a loss of mechanical properties of composites material.

3.4.2 Mechanical Tests

These tests determine the strength, stability, bending and the hardness of the materials. However, the literature from material manufacturers and supplier‘s requirement for incoming inspection of materials often quotes the qualities of plastics in terms of tensile strength, flexural strength, impact strength, hardness, elongation and modulus. These qualities outline the plastics characteristics under tension and its resistance to any change in shape.

The most important mechanical tests are: tensile (ASTM D638), Flexural (ASTMD790), Izod Impact (ASTM D256), Rockwell Hardness (ASTM D785) and Durometer Hardness (ASTM2240).

(i) Tensile Strength

The force necessary to pull a specimen apart before breaking indicates how tough or brittle the material may be. Therefore the tensile test measures the maximum stress that a material can withstand while being stretched or pulled. Plastics materials produce stress-strain curves that offer clear indications of the various points of yielding as the load increased. Thus, there are seven important references that can be derived from a stress-strain diagram. The tensile testing procedure involves placing the test specimen in the testing machine and applying tension to it until it fractures. Stress, strain, young‘s modulus, yield strength and ultimate tensile strength can be determined from the data obtained.

The Stress is the amount of force applied to the test specimen, or the ratio between the forces applied and the cross-sectional area of the specimen. By relating stress to strain, how much the material changes in length, provides information about the rigidity of the material.

Tensile strength = P/A in (N/mm^2) (3.5)

Where: P = Breaking load in kN, A = Cross-section area of sample in mm^2.

The Strain is the change in length in relation to the applied load. This recorded at the bottom of the stress-strain curve.

Strain = Elongation / Gauge length. (3.6)

The test specimens in dumb-bell shape of the required standard dimensions according to ASTM D638 was cut and clamped between the upper and lower jaws of the type “W” Monsanto Tensometer and the machine was loaded manually.

The sample was stretched with the aid of a hand lever attached to one end of the machine until the sample ruptured. The values of the breaking load and elongation was taken accordingly. The test was repeated three times for each sample of the composite and the average value were recorded.

(ii) Elongation

Elongation is the percentage increase of the original length of the rubber sample, as a result of tensile force being applied to the sample itself. It is inversely proportional to hardness, tensile strength, and modulus of elasticity, hence, the greater a materials hardness, tensile strength and modulus, the less it will elongate under stress.

It takes more fore to stretch a hard material having high tensile strength and high modulus, than to stretch a soft material with low tensile strength and modulus.
Natural rubber can often stretch up to 700% before breaking, while fluorocarbons typically rupture at about 300%.

(iii) Hardness Test

This test describes the process of surface deformation of a material due to indentation. This test could be employed by the use of two types of durometer hardness machine i.e. type A and type D. This is used to measure the hardness of a material ranging from soft rubber to hard rubber and plastic.

The "Indentec Universal Hardness Testing Machine Model 8187.5LKV 'B" Rockwell RHF Indentor (1/16" steel ball) with minor load 10 kg and major load 60 kg was used in measuring the hardness using the shore scale according to ASTM 2240. It consists of an indenter, a graduated circular tube and a flat surface which the sample to be tested was mounted. The sample was placed on the flat surface and the indenter was made to make an impression on the specimen material, the load was maintained at a minimum time of 10 to 15 seconds. The test was repeated for about five times and the average values were obtained.

3.4.3 Tribological Properties

(i) Abrasion Test

Abrasion process involves removal of small particles between 1-5µm, leaving behind pits in the surface and then followed by removal of large particles usually greater than 5um.

The Abrasion resistance tests were carried out using the Martindale Abrasion Machine with model no. 11884. A known mass of 30mm diameter sample was subjected to an abrading surface at a constant revolution/speed of 1000rpm for 5minutes each. The percentage weight lost for each tested specimen was determined and recorded after brushing to remove any dust or abrading material adhering to the surface of the specimen. The Percentage weight lost shown in equation 3.6 was used to express the abrasion resistance of the material tested.

IV. RESULTS AND DISCUSSION

4.1 Experimental Results

The various results obtained during the experiments are indicated in tables 1 through 9 below.

4.1.1 Filler Characterization Result

Physical characterization such as Moisture Content, Ash Content and Density were determined and results are presented in tables 1 through 3 respectively.

(i) Moisture Content Test Results

The result of the moisture content is reflected in table 1 below:

Table 1: Moisture Content

Sample	W_1 (g)	W_1 (g)	% Moisture Absorbed
Carbonized PKSp	38.198	38.142	0.15

(ii) Ash Content Test Results

The result of the ash content is shown in table 2 below:

Table 2: Ash Content

Sample	W_1 (g)	W_1 (g)	% Moisture Absorbed
Carbonized PKSp	36.189	36.615	1.18

(iii) Density Test Results

The result of density test is reflected in table 3 below:

Table 3: Density

Sample	Mass (g)	Volume (cm^3)	Density (g/cm^3)
Carbonized PKSp	31.512	30	1.05

4.1.2 Results of Solvent Absorption Test

The various results of Water, Petrol and Diesel absorption is reflected in table 4, 5 and 6 respectively.

Table 4: Water Absorption Test Results

Samples	% swelling Day 1	% swelling Day 2	% swelling Day 3	% swelling Day 4	% swelling Day 5	% swelling Day 6	% swelling Day 7	Average % Swelling
A	0.938	0.940	0.944	0.945	0.946	0.947	0.947	0.944
B	0.714	0.719	0.722	0.724	0.725	0.727	0.728	0.723
C	0.431	0.435	0.436	0.436	0.437	0.738	0.738	0.522
D	0.391	0.392	0.394	0.395	0.397	0.398	0.398	0.395
E	0.350	0.352	0.353	0.354	0.355	0.356	0.356	0.354
F	0.355	0.356	0.356	0.356	0.357	0.358	0.358	0.357
G	0.315	0.316	0.316	0.316	0.317	0.318	0.319	0.317
H	0.281	0.282	0.284	0.284	0.285	0.286	0.287	0.284
I	0.243	0.243	0.244	0.244	0.245	0.246	0.246	0.244
J	0.320	0.320	0.320	0.321	0.322	0.322	0.323	0.321

Table 5: Diesel Absorption Test Results

Sample	% swelling Day 1	% swelling Day 2	% swelling Day 3	% swelling Day 4	% swelling Day 5	% swelling Day 6	% swelling Day 7	Average % Swelling
A	1.156	1.159	1.162	1.163	1.165	1.166	1.169	1.163
B	1.108	1.109	1.110	1.113	1.115	1.116	1.116	1.112
C	1.051	1.052	1.052	1.053	1.054	1.055	1.055	1.053
D	0.764	0.765	0.766	0.768	0.769	0.769	0.780	0.769
E	0.683	0.684	0.686	0.686	0.687	0.688	0.688	0.686
F	0.553	0.553	0.554	0.554	0.556	0.556	0.557	0.555
G	0.488	0.489	0.489	0.491	0.492	0.492	0.493	0.491
H	0.436	0.436	0.436	0.437	0.438	0.438	0.438	0.437
I	0.368	0.368	0.369	0.370	0.371	0.372	0.372	0.37
J	0.471	0.472	0.473	0.473	0.474	0.474	0.475	0.473

Table 6: Petrol Absorption Test Results

Sample	% swelling Day 1	% swelling Day 2	% swelling Day 3	% swelling Day 4	% swelling Day 5	% swelling Day 6	% swelling Day 7	Average % Swelling
A	1.719	1.720	1.722	1.726	1.727	1.729	1.731	1.725
B	1.401	1.403	1.405	1.406	1.407	1.408	1.409	1.406
C	1.202	1.202	1.205	1.206	1.207	1.208	1.208	1.2O5
D	1.174	1.176	1.179	1.180	1.181	1.182	1.184	1.179
E	1.136	1.136	1.137	1.139	1.141	1.142	1.144	1.139
F	1.100	1.102	1.104	1.105	1.106	1.106	1.107	1.104
G	0.981	0.981	0.982	0.982	0.983	0.983	0.983	0.982
H	0.946	0.947	0.947	0.978	0.979	0.981	0.981	0.966
I	0.704	0.704	0.905	0.907	0.907	0.978	0.978	0.869
J	0.703	0.705	0.707	0.708	0.709	0.710	0.711	0.708

4.1.3 Results of Tensile Tests

The results of tensile tests for all the samples are shown in the table 7 below

Table 7: Tensile Properties Result

Sample	Load (N)	Tensile Strength (N/mm^2)	Strain	Elongation (%)	Modulus (N/mm2)
A	680	17	6.61	661	2.572
B	387	9.7	6.74	671	1.439
C	2770	69.25	4.18	418	16.567
D	920	23	6.58	658	3.495
E	720	18	6.59	659	2.730
F	400	10	7.26	726	1.377
G	520	13	6.57	657	1.978
H	320	8	6.80	680	1.978
I	480	12	6.50	650	1.864
J	320	8	6.60	660	1.212

4.1.4 Results of Hardness Tests

The various results of Hardness Tests on durometer scale is documented in table 8 below

Table 8: Hardness Test Results

Sample	1st Reading	2nd Reading	3rd Reading	4th Reading	5th Reading	Average Hardness(shore A)
A	36	34	33	40	36	35.80
B	25	30	27	25	28	27.00
C	37	38	34	36	36	36.20
D	41	40	40	41	39	40.20
E	22	23	24	22	19	22.00
F	36	34	33	35	35	34.60
G	65	65	64	66	63	64.60
H	35	40	39	36	36	37.20
I	36	35	33	36	33	34.60
J	30	30	28	29	26	28.60

4.1.5 Results of Abrasion Tests

The results of abrasion tests are documented in table 9 below

Table 9: Abrasion Resistance Result

Sample	Initial weight	Final weight	Change in Weight	Weight loss (%)
A	4.648	4.582	0.066	1.42
B	4.743	4.601	0.142	2.99
C	5.536	5.489	0.047	0.85
D	4.359	4.326	0.033	0.76
E	4.265	4.240	0.025	0.59
F	4.457	4.320	0.137	3.10
G	4.474	4.399	0.075	1.68
H	4.578	4.514	0.064	1.39
I	4.353	4.319	0.034	0.78
J	4.009	3.981	0.028	0.70

4.2 *Discussion of Results*

4.2.1 Discussion of Physical Properties of Samples

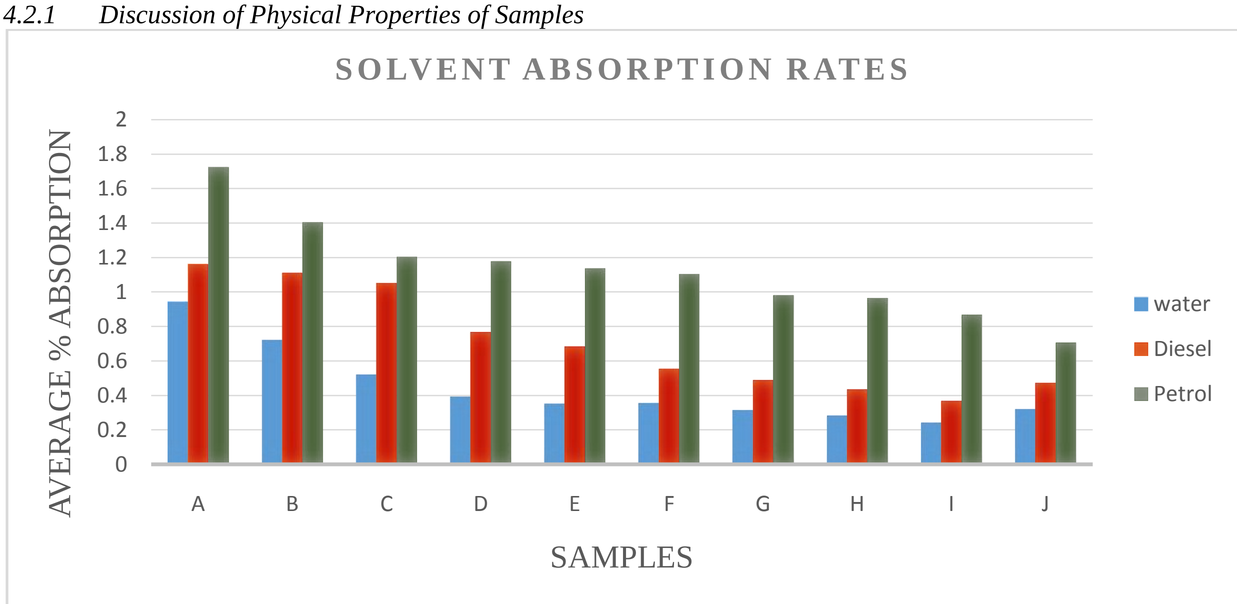

Figure 1: Solvent Absorption

Figure 1shows the average percentage swelling rates after seven days analysis of produced Natural Rubber (NR) composite slabs immersed differently in Petrol, Diesel and Water beakers.

Petrol, Diesel and Water percentage absorptions had highest values of 1.725%, 1.163%, and 0.944% respectively in sample "A" which read the highest average percentage swelling rate amongst all ten samples (A-Z). This indicates more absorption in sample without filler loading. The result showed that the gasoline absorption by the rubber vulcanizate will lead to the reduction in both the rupture stress and rupture strain if allowed to stay in the solvent for a longer period. The effect of Diesel on the vulcanizate, showed that the loss of weight is attributed to dissolution of soluble contents like plasticizers, stabilizers or additives. For water, the decline in average percentage swelling rates as the filler loading increases indicates good compatibility of NR and carbonized palm kernel shell powder. Thus, confirming composite as hydrophobic.From the graphical representation comparative analysis, similar trends were observed in terms of decrease in the average percentage swelling of the three solvents across the tested composites that is from samples “A” through to “J”, confirming the reduction effect of the filler as loading increases. Military Combat Boots are often used in wet scenarios than in other solvents (petrol and diesel) as experimented in this work. The results obtained indicated that for seven days the composites were immersed in the various solvents, average percentage swelling of Natural Rubber in water were all less than 1% giving the mean value of the average percentage swelling for nine days testing of samples A to J as 0.45%.

4.2.2 Discussion of Mechanical Properties

The mechanical test carried out on the composite samples include: Tensile strength, Young’s Modulus, Elongation, and Hardness Strength are shown in figures 2 – 5.

i. Tensile Strength

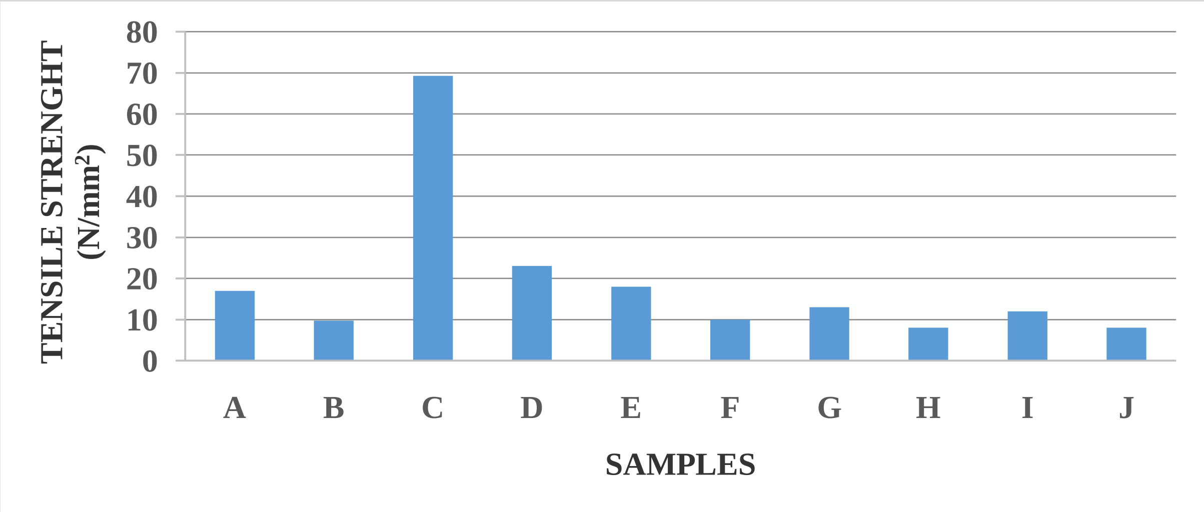

Figure 2: Effect of PKS on the Tensile Strength of the Rubber Composite

From figure 2, it was observed that the tensile strength of the NR/PKS composite increases as the fibre loading increases until optimum value was obtained at sample C; with an ultimate tensile strength of 69.25N/mm^2 there after the strength decreases. The decrease in tensile strength is attributed to low wettability of the filler by the matrix beyond the optimum point. It could also be inferred that since the tensile strength are higher compared to the NR matrix alone (Sample A), therefore there is need to introduce the PKS filler to increase the stiffness of the Material.

ii. Young’s Modulus

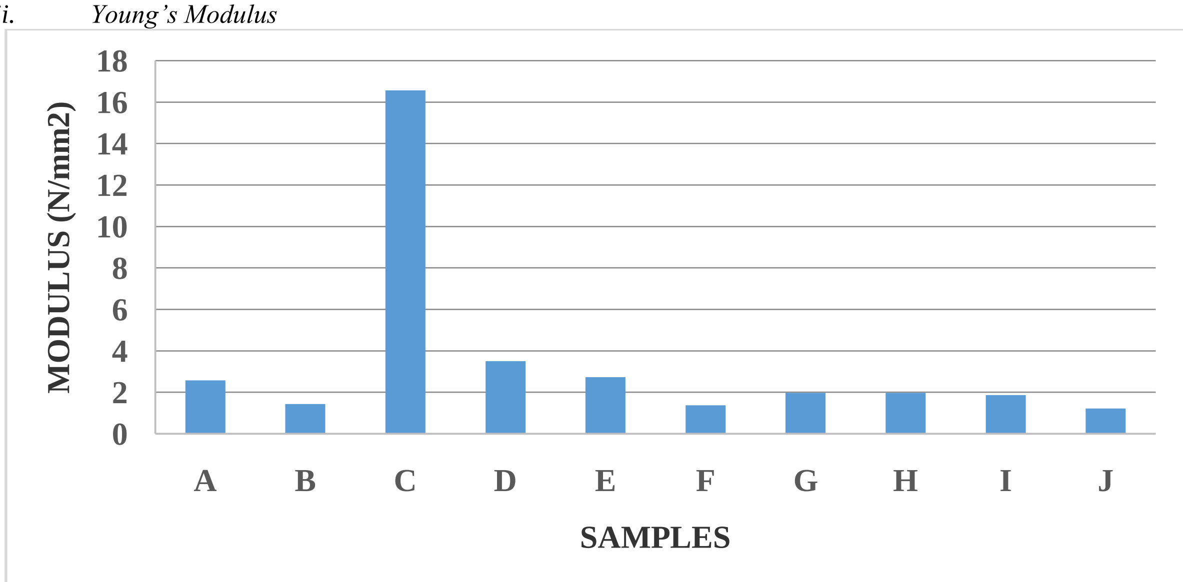

Figure 3: Effect of PKS on the Tensile Modulus of the Rubber Composite

Figure 3 illustrate the effect of fibre loading on the tensile modulus of the composites. Tensile modulus of the sample increased as the filler loading increased and therefore decreased at higher filler loading. The highest modulus of 16.567 N/mm^2 was obtained at sample C. The tensile modulus was mainly influenced by the shape factor and particle size of PKS powder. The variation in tensile modulus responses of composites is attributed to the extent of dispersion of filler in the matrix phase; agglomeration and incorporation between particles and matrix may also be factor for the trend.

iii. % Elongation

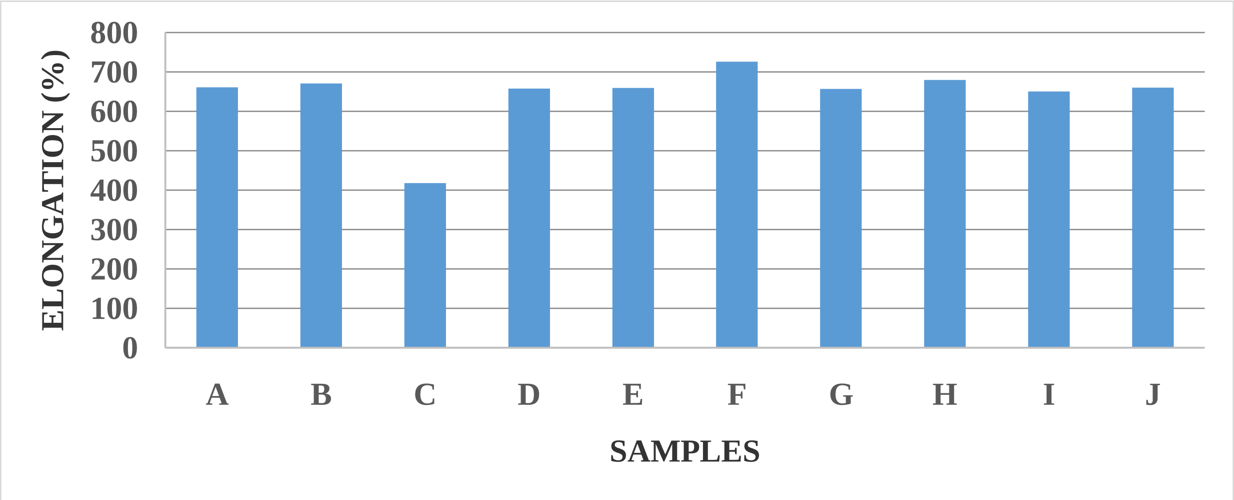

Figure 4: Effect of PKS on the Percentage Elongation of the Rubber Composite

Figure 4 above shows the plot of percentage elongation at fracture of the composites. The values obtained are very close except for sample C which is relatively stiff. The values of elongation at fracture of samples generally increased as the filler loading increased from sample B to sample J. However, elongation at fracture composite peaked at sample F with 726 % elongation and decreased as the filler loading increased having the lowest elongation at sample C with percentage elongation of 418%. The trend of the composites' elongation can be attributed to the effect of adhesion between the fillers and NR and better dispersion.

iv. Discussion of Hardness Properties of Samples

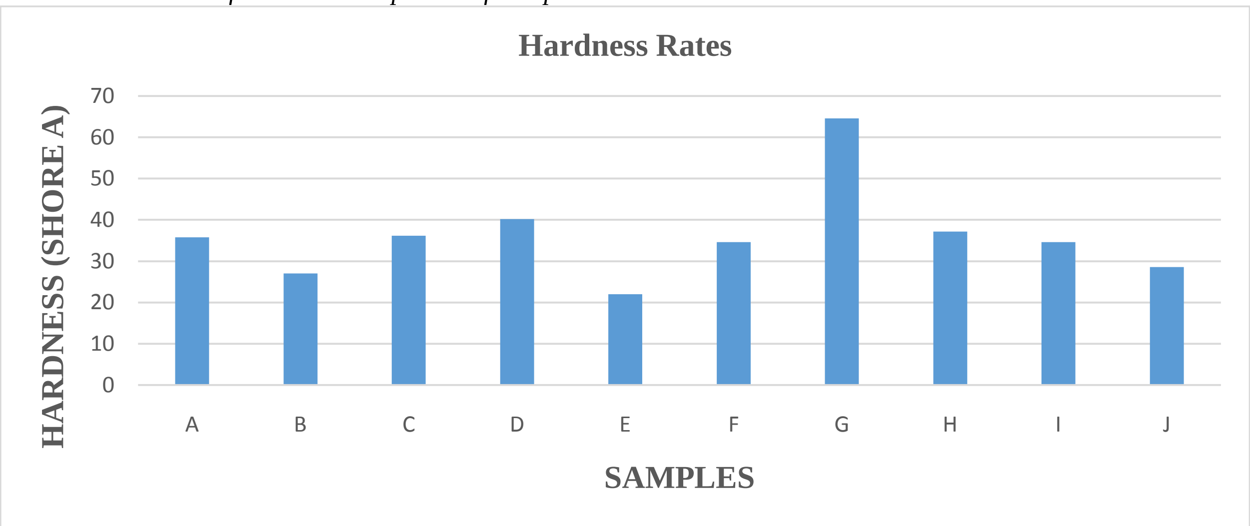

Figure 5: Effect of PKS on the Hardness of the Rubber Composite

Hardness is the relative resistance of the surface of samples to indentation or penetration by an indentor of specified dimension under a specified load. Figure 5 indicates the results of the influence of PKS additives on the prepared samples.

The hardness of the PKS/NR composite was found to be maximum with a value of 64.6 Shore A for sample G and a minimum value of 22.00 Shore A for sample E, indicating that 'E' possesses the most ability to absorb shock. It can be seen that the value of the hardness for the composites increased by a maximum of 48.7 %. This can be attributed to the fact that at lower particle size the voids in the composites are filled therefore facilitating a smoother surface for indentation. Also, this shows that the filler used PKS is a good reinforcing filler in providing the necessary hardness required for composite. Sample E, is the best sample that exhibited required softness and shock absorbent ability.

4.2.3 Discussion of Tribological Properties

Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear.

(i) Abrasion Resistance Result

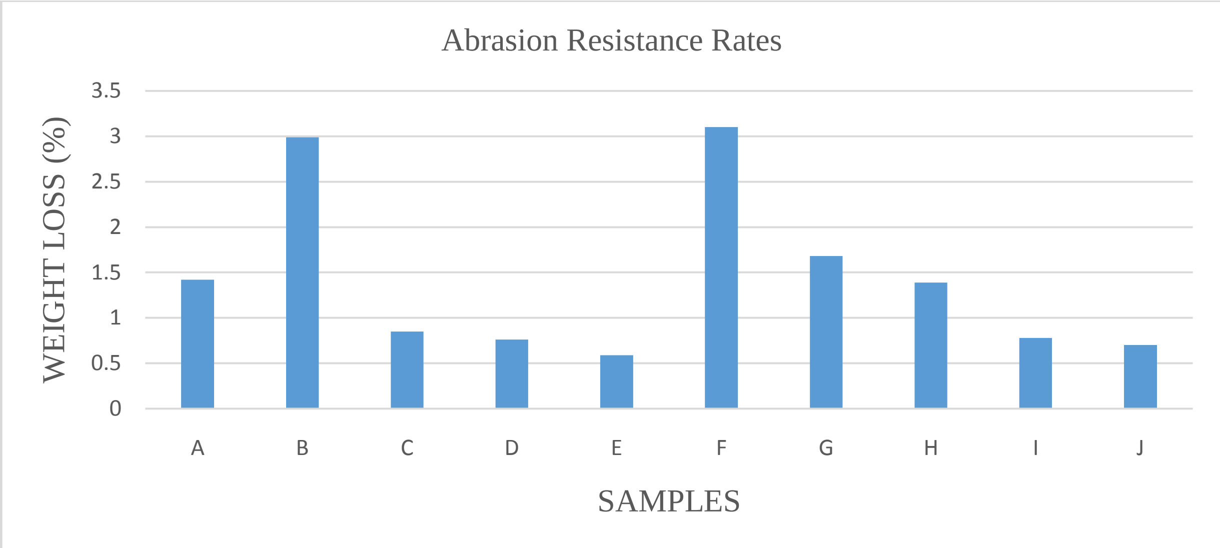

Figure 6: Effect of PKS on the Abrasion Resistance of the Rubber Composite

Figure 6 shows results of abrasion resistance for the produced samples. Abrasion resistance is ability of material to resist wear under constant shear force. Percentage weight loss was used to express abrasion resistance of the composites. Higher percentage weight loss of 3.2 % was observed for the sample F followed by 2.99 % at sample 'B' whereas sample 'E' has the lowest percentage weight loss at 20 g. Better abrasion resistance was observed at sample E with 0.59 % weight loss, this could be due to proper filler-matrix distribution and strong interfacial adhesion that could have formed in the composite since filler–matrix composition has effect on the distribution and interfacial adhesion of the filler and the matrix.

4.2.4 Discussion of the Physical Properties of Produced Combat Boot Sole Prototype

From all the test carried out, it was observed that sample "E" and "G" with 20g and 30g of CPKSp filling possessed close optimum properties. Sample "E" was chosen due to its very good abrasion resistant property, lowest hardness property value, which qualified for required shock absorbent properties and a considerable percentage elongation etc. Thus, its formulation as indicated in table 3.1, was used in the production of the combat boot sole prototype.

Table 10: Weights and Corresponding Densities of Tested Combat Boot Soles, Standard Size 9

S/No	Type	Weight per pair (g)	Density (g/cm³)	Colour	Flexibility
1	Foreign EVA Sole	638	0.778	Light brown	Flexible
2	Military/NDA Cadet Wellco Boot Sole	754	0.877	Black	Less flexible
3	Army Boot Sole (PVC)	856	0.973	Black	Rigid
4	NR/Carbonized PKSp	488	0.697	Black	Flexible

Plate 8: Produced combat boot sole prototypes showing inner sole

Plate 9: Produced combat boot sole prototypes showing studs

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions:

The following conclusions can be drawn from this work:

i. In this study, some Combatants and Cadets were randomly interviewed to determine the unpleasant effect resulting from the boot they use. Fifteen Military Men, Ten Civil Defence Personnel, Ten Mobile Policemen and Forty NDA Cadets (75 persons) were selected and interviewed in all. Afterwards, ninety percent (90%) of them agreed that the combat boot they use had some unpleasant effects which caused a high level of discomfort. In most cases, these discomforts usually led to injuries that consequently, affected their work, routine training, studies and official assignments.

ii. It was discovered that the cause of feet and lower limb related injuries amongst the study group, was the painful involuntary contraction of the muscles in the feet region as a result of frequent combat boot usage during work, training or combat engagement that usually led to physical damage of their feet and fatigue fracture in the lower limb.

iii. The identified types of injuriy are Ankle Sprains, Foot Blisters, Trench Foot, Knee Pain, Rucksack Palsy, Ankle Fracture and Ankle Dislocation.

iv. Three types of combat boot soles commonly used by the interviewed combatants were studied, namely; Foreign Made Canvas Combat Boot whose sole is produced with Ethylene Vinyl Acetate, EVA (used by Civil Defence and Mobile Police), Wellco Combat Boot sole (used by the NDA Cadets and Military Men, produced with Synthetic Rubber and EVA, and a locally procured Army Boot sole from the After- Rail Central Market Kaduna, produced with Polyvinyl Chloride, PVC (used by both Military and Paramilitary personnel especially for sole replacement). Subsequently, in an attempt to reduce the rate of injury occurrence within the military and paramilitary population it was decided in this study to produce a lighter weight, shock absorbent, ductile but rugged outsole.

v. Nine slabs were produced from the blend of Natural Rubber and Carbonized Palm Kernel Shell powder (CPKSp), after characterization of CPKSp, they were subjected to mechanical, physical, chemical and tribological tests.

vi. The filler (CPKSp) characterization results were; 0.15%, 1.18% and 1.05g/cm3 for moisture content, ash content and density respectively. The tensile properties result indicated that sample 'C' had the highest tensile strength of 69.25N/mm² and lowest tensile strength of 8.00N/mm² for both samples 'H' and 'J'. The percentage elongation peaked at sample 'F' with 726% and had lowest elongation for 'C' with 418%. The sample with the highest modulus of elasticity was 'C' with 16.57N/mm² and minimum of 1.21N/mm² for J. The hardness test results showed that sample 'G' have the highest value of 64.60 shore A, and sample 'E' has lowest shore A hardness value of 22.00, hence sample 'E' possesses best shock absorbent property. The mean values of the average percentage swelling of natural rubber after immersion in water, diesel and petrol for seven days are 0.45%, 0.711% and1.128% respectively. The results of abrasion tests showed that sample 'E' had the best abrasion resistance value with 0.59% weight loss.

vii. An aluminum mould, with the dimension: length x width x breadth (355mm x 245mm x 30mm) was produced with the intended sole pattern through sand casting method. It was designed to produce a standard size 9 outer sole. The formulation for the slab produced with 20g filler (sample E) loading was used in producing the combat boot sole prototype.

viii. The physical properties (weights) of each pair of sole samples studied earlier were compared with that of the combat boot sole prototypes produced, and the results showed that the foreign sole produced with EVA weighed 638g. The NDA Cadets boot sole weighed 754g and the military boot sole procured from the market (made of PVC), weighed 756g and the prototype sole produced in this research weighed 488g.

ix. Production processes including; selection and preparation of raw materials used, production of sole mould, power supply, machines efficiency, knowledgeable personnel and cost of production were factors that affected the production reliability of produced sole prototype.

5.2 Recommendations:

The following recommendations for future work are hereby proposed;

i. The use of Mild Steel mould instead of Cast Aluminum to produce the sole should be investigated to eliminate the various problems associated with the use of aluminum mould.
ii. A rubber blend with thermoset polymer such as phenolic resin could be utilized for the production in order to improve on the mechanical properties such as the modulus, tear and wear resistance.
iii. Use of Crepe Natural Rubber for production should be explored.
iv. Weight borne by soldiers should be directly proportional to their Body Mass Index.

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