FORMULATION OF POWDERED ALUMINA FOR BODY ARMOUR APPLICATION

BY

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TO

DEPARTMENT OF MECHANICAL ENGINEERING,

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DECLARATION

I hereby declare that this project has been carried out by me, **BADMUS, JUBRIL AYOTUNDE,** and submitted to the Department of Mechanical Engineering, Federal University Oye-Ekiti in partial fulfilment for the award of Bachelor of Engineering (BEng) degree in Mechanical Engineering.

MEE/11/0404

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CERTIFICATION

This is to certify that this proposal was prepared by BADMUS, JUBRIL AYOTUNDE (MEE/11/0404) under my supervisor, in partial fulfillment of the requirements for the award of a Bachelor of Engineering (B.Eng) degree in Mechanical Engineering, Federal University Oye Ekiti, Ekiti State, Nigeria.

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DEDICATION

This report is dedicated to Almighty Allah for being a source of knowledge and inspiration.

ACKNOWLEDGEMENT

My profound gratitude goes to Almighty Allah the most high, the first and the last, the Lord of the universe who is worthy of all praises, honour and glory who made my existence a possibility and has so far been in the control of my life and also promises to be in control forever.

My acknowledgement finally goes to my parents Mr. and Mrs. Badmus, I pray they live long to reap their fruit of labour.

My lecturers as well my colleagues for their humanly attention and lovely gestures.

ABSTRACT

Body amour describes the object that is worn or carried to provide an individual protection against external energy. This research work was carried out to formulate powdered alumina for body amour application. Alumina powder (Al_2O_3), magnesium oxide (MgO), calcium oxide (CaO) and polyvinyl alcohol (PVA) were the materials used in the formulation procedure for the research work, the materials were mixed thoroughly to form six different formulation samples; binder and alumina powder in each samples were varied. The material were formed in the mould (100mm x 50mm x 30mm and 50mm x 50mm x 30mm) by uniaxial pressing force of 300KN for physical and mechanical tests (percentage shrinkage, density, water absorption, compressive strength, hardness and modulus of elasticity). The six green samples were sintered in an electric furnace at 1500°C for one hour. It was observed that sample B (1% PVA) and sample E (4% PVA) showed the best physical properties among the six samples. For the mechanical test, sample A showed highest hardness value (11.2 GPa) but low values in modulus of elasticity (243 GPa) and compressive strength (2208 MPa) while sample B showed highest value in modulus of elasticity (284 GPa) and compressive strength (2454 MPa), but sample C and D showed low value in it. The microstructure of the sample B (with best mechanical properties) was observed to have shown a uniform solid distribution. Sample B was therefore found to be the best for potential body armour application with regards to its interest physical, mechanical and microstructural properties.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 General Background of the Study

The development of protection for stationary and mobile structures against ballistic impacts, explosives, radiation, chemical and biological agents, is an important task in defence applications (Yaziv *et al.*, 2001). It has being established in the last three decades that ceramic facing structures represent a group of light armour. Consideration of ballistic protection system must take into account several factors (Medvedovski, 2002). These factors include threat level, multi-hit performance (Bless, 1998), environmental conditions, space limitations, manufacturing challenges, cost and weight limitations, physical properties of facing material and backing material, which determine the overall ballistic performance of the system (Hohler *et al.*, 2001) .

Body armour is the term used to describe items that are worn or carried to provide an individual protection against external energy. In military and law-enforcement environment, this energy is principally in the form of impact by non-penetrating projectiles or blows, blast waves from explosions, and penetrating missiles (Bless, 1998).

A ballistic vest, bullet vest or bullet resistant is an item of personal armour that helps absorb the impact from fire projectiles and shrapnel from explosions. Soft vest are made from many layer of woven or laminated fibres and it is capable of protecting the wearer from a small calibre handgun and shotgun projectiles and small fragment from explosive such as hand grenade (Adze, 2014). One of the prospective application of ceramic composites is in ballistic protective structures. Ceramic composite armour was initially developed during the Vietnam War for use, as helicopter armour and personnel armour (Plihal *et al., 2012*). The requirements for the armour were light weight and the capability to defeat small calibre armour piercing (AP) projectiles. Several different ceramics were developed and tested for this application. It was found that alumina oxide (Al_2O_3), silicon carbide (SiC) and boron carbide (B_4C) had the best combination of properties to meet the requirements (Yaziv *et al.*, 2001).

Ceramic materials require sintering in high temperature kilns where the ceramic microstructure is formed by consolidation of the original powder (Breviary, n.d). The characteristic properties of the ceramic material are created by the sintering process at temperatures of 1600°C for alumina (Breviary, n.d).

Ceramic composites have a variety of applications in diverse engineering areas where they are subjected to high mechanical and thermal loads. Armour systems require advanced solutions, relying on combination of materials of different natures to provide adequate ballistic protection and weight saving (Yaziv *et al.*, 2001). With the development of lighter and more durable materials for the ballistic vest, protection will be beefed up and guaranteed as well, as long as it will bring about a decrease in casualties on the battle field amongst military/ other security troops (Adze, 2014).

Hence, it is on this note that this research work is directed at the production of ceramic armour hardware for the protection of law enforcement agent like police, state security service (SSS) and civil defence corps.

1.2. Statement of Problem

Majority of the ballistic vest in use by the Nigerian soldiers are imported from foreign countries (Cynthia, 2015). Also, Nigeria has overtaken Iraq, Afghanistan and Latin American countries as the world's biggest importer of bullet proof (armoured) vehicles. It is estimated that about 30 percent of customers for armoured vehicles worldwide come from Nigeria. In the last few years, manufacturers of armoured vehicles have exported an estimated 800 to 900 units to Nigeria at the cost of more than N60 billion (Bukola, 2003).

Every year, about 60 sworn police officers are shot to death in the line of duty. At same time, about 20 are saved by wearing armour. Had all the officers shot in recent years been wearing armour when shot, another 15 per year would likely have been save from gunshot wounds (OTA- Congress, 1992).

In Nigeria, we have not been able to produce this ballistic vest for our used, which we can eventually offer maximum protections from firing flying bullets on the battle field (Adze, 2014). The inference one can draw from this is that we only depend on the protection other countries offer to us. The country only endanger the lives of it citizenries if there in an international, dispute, bilateral or social-economic problem with any of the counties we procure the hardware. Therefore, it is necessary to intensify research toward armour technology in Nigeria.

1.3 Research Justification

This research is to domesticate knowledge on using alumina as a material for armour technology as the need of armour wears by security operatives is indispensable on strategic assignments involving weapon flying bullets. As Nigeria solely depends on the importation of armour hardware, formulation of light ceramic plate using alumina for possible armour applications would adding to Nigeria's security independence and it would generate employment.

1.4 Aim and Objectives

1.4.1 Aim

The aim of the project is to formulate and evaluate the mechanical and microstructural characteristics of the sintered alumina ceramic for possible armour applications.

1.4.2 Objectives

Formulation and development of alumina ceramic samples

I. Formulation and development of alumina ceramic samples

II. Physical, mechanical (density, porosity, compressive strength, hardness, modulus of elasticity) and microstructural characterizations of the sintered samples produced

III. Analysing and comparing the result of the developed ceramic samples with the established/standard results

IV. Recommendation for further research work

1.5 Significant of the Study

From the history ceramics have being considered one of the most important material for light weight armour application due to their low density, high compressive strength, and hardness (Silva *et al.*, 2014). Hence, the significant of studying ceramic material on armour application is to establish and domesticate the technology of producing ceramic component of body armour, bulletproof doors and bulletproof cars.

Hence, saving the lives of the country's law enforcement, ordinary citizens and huge amount of money on importation of armour hardware.

1.6 Scope

This research looks to the formulation of light weight ceramic plate using pure alumina particulate and the mechanical and microstructural characterizations of the developed samples for possible amour applications.

CHAPTER TWO

2.0 Literature Review

2.1 Introduction

Although discussion of "bullet proof" and "pistol proof" plate armour exist as early as the 1500s, the first ballistic armour was invented in Korea in the 1860s (Adze, 2014). During the time of increased threat from the western armies, Korea's government directed the development of bullet proof armour. Two national armour developers through trial and error produced garments consisting of multiple fold of cottons which could protect against the gunfire of that era, although the garment were susceptible to fire (Plihal *et al.*, 2012).

Towards the end of the 19th century, inventors in Arizona and Illinios produced bullet vest made of silk, which where proven to stop the rounds from black powder handguns. A vest of this type safe the life of King Alfonso XIII of Spain 1901 (Plihal *et al.*, 2012).

The Second World War necessitated further development in personal body armour. Typically, the models of armour developed by the United States and other nations were too heavy and cumbersome for ground troops. Two specific offshoot of the search for effective armour came in form of American flak jackets for aircraft crews, which were design to stop shrapnel but not bullet, and the SN-42 body armour developed by the red army for the tankers and engineers. Improvement to the ballistic armour were made in time for the Korean and Vietnam wars, but the garments were still not effective on the field (Plihal *et al.*, 2012).

The first substantially ballistic armour was produced by a company called America body armour, founded in 1969 and working with smith and Wesson. America body armour created a "barrier vest" of nylon with multiple steel plates. It is considered the first widely used police vest, but was considered as significantly more costly than what many officers or department could afford (Jassica *et al.*, 2010).

Modern ceramic science evolved from 1700's from the European development of porcelain (Adze, 2014). Chinese porcelain first created in 600AD had reached superb standards by the mid-13th century. Western demand for this material was insatiable and Europeans tried assiduously to reproduce it. The two major problems were that the high temperatures needed (at least 1350 °C) could not be reached in the primitive European kilns (Adze, 2014), and the Chinese were adept at keeping details of the ingredients secret. At the beginning of the 18th century in Saxony, Bottger and Tschirnhaus developed a furnace to reach the appropriate temperature and then after years of experimentation, in January 1708, Bottger was able to produce high quality porcelain through a mix of white kaolin and alabaster (Adze, 2014).

In the 1870's refractory materials able to withstand extremely high temperatures were developed using materials made from lime and magnesium oxide (or magnesia). This was a key enabler for the future development of industries dependent on high temperature processes - such as iron and steel, glass, nonferrous metals, the production of lime and cement, and ceramics (Adze, 2014).

In 1887 Thomas Edison directed what was arguably the first example of advanced ceramic research. He directed the testing of a broad range of ceramic materials for resistivity for use in his latest invention, the carbon microphone (Adze, 2014).

The long process of moving ceramics from a craft to a science based technology conducted under the direction of engineers was underway in the 1800s and has continued to the present day Watchman cited (Cahn, 2001). Since then ceramics have been developed for an immense range of advanced applications were materials are required that can resist thermal shock, provide high temperature and electrical insulation, act as abrasives, have a better (compressive) strength weight ratio. More recent breakthroughs have included: In 1965, the development of photovoltaic cells which convert light into electricity (solar cells); In 1987, the discovery of a superconducting ceramic oxide with a 60 $^{\circ}$C higher critical temperature than metallic superconductors with potential use in integrated circuits in high speed computers, recently in the early 1990s the development of a range of ceramic materials called 'smart' materials that sense and react to variable surface conditions. An example of use is in the triggering of airbags. The range of ceramics developed to exploit their special properties to meet a wide range of demanding engineering applications is vast. It now includes:

2.1.1 **Electrical ceramics**

Phosphors for cathode ray tube screens which have been used until recently for computer, TV, radar and oscilloscope screens, and computer monitor;

- Piezo electric (used in sonar and ultrasonic), pyroelectric, electro-optic and magnetic ceramics
- Ceramic conductors (e.g. the varistor), supersonic conductors, superconducting ceramics.
- Ceramic capacitors

2.1.2 **Magnetic ceramics**

- Ferrite as the ceramic core of the 1948 giant synchrotron (replacing the metallic core).
- Computer memory
- Telecommunications.

2.1.3 **Thermal insulation and refractory materials**

- Refractory materials
- Ceramic tiles for thermal insulation against high re-entry temperatures of the space shuttle

- Alumina ceramics for missile and rocket nose cones
- Silicon carbide and molybdenum disilicide for rocket nozzles.

2.1.4 Nuclear power

- Fuel elements as a ceramic compound
- Control rod elements in ceramic form.

In line with other advanced materials the recent change in focus from a micro to a Nano-structured approach has resulted in engineering ceramics with high temperature super-plasticity; better mechanical strength (fracture behaviour approaching quasi ductility, strength comparable to single crystals, improved reliability and improved high temperature properties and a range of new functional properties such as high electrical conductivity and elevated thermal conductivity (Sajgalik, 2004).

2.2.0 Armour Materials

Armour materials can be classified into three main groups, namely metallic, ceramic and composite materials.

2.2.1 Metallic Armours

Metals are still the most widely used materials in armour design. The main advantage of these materials is that, they are capable of carrying structural and fatigue loads while offering efficient protection. They are less expensive compared to the other materials.

The most commonly used metallic material in armour fighting vehicles is steel. The main properties such as toughness, hardness, good fatigue strength, ease of fabrication and joining and relative low cost make it a popular material for armoured vehicle hulls (Hazell, 2006).

Steel armour can be studied in four main groups which are Rolled Homogeneous Armour (RHA), High Hardness Armour (HHA), Variable Hardness Steels and Perforated Armour (Hazell, 2006).

2.2.1.1 Rolled Homogeneous Armour (RHA)

Rolled homogeneous armour (RHA) is usually used in depth of penetration testing as a benchmark material (Hazell, 2006). Therefore it is used to describe and compare the performance of different armour systems or materials chemical composition (Hazell, 2006). The classification of RHA according to UK Ministry of Defense Standard for Armour Plate (DEF STAN, 2004) are given in Table 2.1 and Table 2.2.

Table 2.1: Composition of RHA

C	Mn	Ni	Cr	Mo	S	P
0.18-0.32	0.65-1.50	0.05-0.95	0.00-0.90	0.30-0.69	0.015 (max)	0.015 (max)

Source: (DEF STAN, 2004).

Table 2.2: Classification of RHA

Classification	Description	Hardness (BHN)	Tensile Strength (MPa)	Elongation (%) Min
Class 1	Readily weld-able steel subjected to structural loads	262-311	895-1,050	15
Class 2	Readily weld-able steel to protect against AP ammunition.	255-341	895-955	14-16
Class 3	Readily weld-able higher hardness steel manufactured in thin sections.	470-540	1,450-1,850	8
Class 3A	Readily weld-able higher hardness steel manufactured in thin sections.	420-480	1,200-1,600	9
Class 4	Higher carbon and alloy content higher hardness armour for thick sections.	475-605	1,450-2,000	7
Class 5	High alloy content armour with very high hardness used for special applications such as perforated armour.	560-655	1,800-2,400	6

Source: (DEF STAN, 2004).

2.2.1.2 High Hardness Armour (HHA)

High hardness armour (HHA) on the other hand, is the name given to a class of homogeneous steel armour which have hardness values exceeding 430 BHN (Hazell, 2006).

2.2.1.3 Variable Hardness Steel (VHS)

Variable hardness steel plates introduces some advantages with varying through thickness properties. By surface hardening one side of a thick low-carbon steel plate, it is possible to incorporate both hard disruptive and tough absorbing properties in a single material (Hazell, 2006).

The main advantage is that, the more ductile backing layer is able to arrest crack propagation in the armour plate while the hard front layer is able deform or fracture the threat. The effectiveness of dual-hardness armour (DHA) is given by a comparison in Table 2.3 (Ogorkiewicz, 1991). It can be seen that DHA is more efficient compared to HHA in defeating steel cored 7.62 AP bullet.

Table 2.3: Density, thickness and areal density values required to protect against 7.62 mm AP bullets at normal incidence.

Armour steel	Density (kg/m^3)	Thickness1 (mm)	Area Density (kg/m)
HHA (550 BHN)	7830	14.6	114
HHA (550 BHN)	7850	12.5	98
HA (600-440 BHN)	7850	8.1	64

Source: (Ogorkiewicz, 1991).

2.2.1.4 Armour Perforation

In perforated armour, holes are introduced into the steel plates. These holes in high hardness steel plate has been shown to be an effective way of disrupting and fragmenting incoming projectiles. This mechanism can be regarded as edge effect (Chocron *et al.*, 2001) has studied the impact of the 7.62 mm APM2 projectile against the edge of a metallic target and a photograph of a fractured core due to aforementioned edge effect is given in plate 2.0.

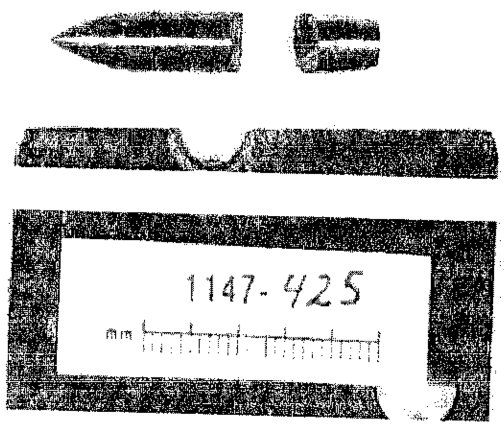

Plate 2.0: Photograph of fractured core due to edge effect (Chocron *et al.*, 2001).

2.2.1.5 Aluminum Alloys

Aluminum alloys also provide a versatile choice for an armour design engineer. The main advantage is that, it has a relatively low density while the tensile strengths range from 60 – 600MPa. It can be deduced that equal mass of aluminum armour will have a larger volume compared to steel, which leads to improvement in rigidity. Material properties of some commonly used aluminum alloys are given in Table 2.4 (Hazell, 2006).

Table 2.4: Material properties of some aluminum alloys currently used in AFVs.

Alloy	Proof Strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Hardness (HV)
Type 5083	(0.1 %) 278	386	6	~100
Type 5017	(0.1 %) 278	490	8	~160
Type 5039	(0.2 %) 420	475	10	~150

Source: (Hazell, 2006).

However, there are some disadvantages associated with aluminum alloys. The harder alloys that are suitable as armour are susceptible to stress corrosion cracking (Hazell, 2006). This type of failure occurs when the aluminum alloy is attacked by a corrodant while it is subjected to tensile stress. The magnitudes of stresses required to start a failure is lower than that of yield strength and the residual stresses induced during machining, assembly or welding can lead to failure.

These alloys also possess a lower spall strength than steel so that they are prone to scabbing. This makes it necessary to employ a spall liner behind the armour.

The ballistic grade form (Ti-6Al-4V) of titanium also provides a good alternative to steel. It possesses a relatively low density (4.45 g/cm^3) while it maintains high strength and hardness (UTS 900 - 1300 MPa, BHN 300 - 350). However, high cost related with titanium alloys is a prominent shortcoming.

2.2.2 Ceramic Armours

It can be anticipated that the resistance of a given material to penetration mainly depends on its compressive strength (Rosenberg *et al.*, 2009). Ceramic materials, which possess high compressive strength and hardness values are good candidate materials as for the armour designer because of their relatively low densities (Hazell, 2006).High strength ceramics such as alumina, boron carbide and silicon carbide exhibit compressive strengths that are an order of magnitude higher than those of metals. Then, it seems possible to make an assumption that ceramic faced targets will be efficient for armoured protection (Rosenberg, 2009).

The costs of ceramic tiles are taken into consideration besides its performance. A comparison of some ceramic materials with prices are given in Table 2.5 (Roberson, 2004).

Table 2.5: Relative cost of ceramic materials for armour applications.

Ceramic	Bulk density (kg/m^3)	Hardness (HV)	K_{IC}[a] ($MPa.m^2$)	Relative Cost
98(%)Al_2O_3	3,800	1,600	4.5	1.0
RB[b] SiC	3,100	3,200/2,200	~4.5	2.5
Sintered SiC	3,150	2,700	3.2	4.5
HP[c] SiC	3,220	2,200	5.0	9.0
HP B_4C	2,520	3,200	2.8	16.0

Source: (Roberson, 2004).

a = Fracture Toughness
b = Reaction Bonded
c = Hot Pressed

2.2.3 Polymeric Armours

Polymeric composite materials possess high specific strength and specific stiffness and they are able to absorb significant part of kinetic energy induced by projectile impact. They also have relatively lower densities (Adze, 2014). These materials consist of laminates of matrix bonded reinforcing fibers. The function of the matrix is to provide a medium for the diffusion of load to the stronger and stiffer fibers (Adze, 2014).

Typical fiber materials are S-glass, E-glass, aramid, carbon and boron. Some properties of these materials are presented in Table 2.6 (Edwards, 2000).

Table 2.6: Properties of some fiber materials.

Fiber	Bulk density (kg/m^3)	Tensile strength (MPa)	Young's modulus (GPa)	Failure strain (%)
Aramid (low modulus)	1440	2990	60	3.6
Polyethylene (high modulus)	970	3200	99	3.7
E-glass	2600	3500	72	4.8
S-glass	2500	4600	86	5.2
Carbon (high strength)	1780	3400	240	1.4

Source: (Edwards, 2000)

2.3 Armour Configurations

Armour configurations can be classified in three main groups according to the way they treat the threat; these groups are passive, reactive and active armours (Tansel, 2010).

2.3.1 Passive Armours

Passive armours are designed to absorb the kinetic energy of a kinetic energy projectile or a shaped charge jet. Special combinations of high strength materials and geometrical designs are used to achieve desired mechanisms against aforementioned threats (Tansel, 2010). From the experience of the author, known types of passive armours are listed below.

2.3.1.1 Sloped Armour

These armours are placed obliquely rather than having a vertical surface. The thickness of the armour can be increased by this way. The second purpose is to ricochet or deflect incoming Kinetic energy threats.

2.3.1.2 Spaced Armour

It's commonly used to defeat shaped charge jets by increasing the distance the jet has to travel to penetrate the armour configuration. Moreover the internal layers can be designed to tumble and deflect incoming Kinetic energy threats.

2.3.1.3 Slat Armour

It works by holding off the shaped charge device from the skin of the vehicle, and increase the way the jet has to travel so that stand-off effect can occur.

2.3.1.4 Composite Armour

These armours make use of special combinations of steels, ceramics and other materials to absorb and diffuse the damage caused by the threat.

2.3.2 Reactive Armours

Reactive armours make use of elements which are sandwiched between two metal plates (Adze, 2014). They react upon the impact of a threat and use special mechanisms to defeat the threat. These armours can be classified as follows:

2.3.2.1 Explosive Reactive Armour

It consists of a sandwich with a front and a rear plate of identical or different thickness and of identical or different materials, with a layer of high explosive between generally arranged at an angle to the attack direction (Held, 1970). When a projectile with enough kinetic energy hits, reactive element will be initiated and plates will be accelerated outward.

2.3.2.2 Non Explosive Reactive Armour

It is very similar to explosive reactive armour but it includes an energetic material instead of a high explosive. This energetic material reacts in a lower order then detonation, therefore smaller pressures are generated.

2.3.2.3 Non Energetic Reactive Armour

It uses non-energetic materials such as elastomers instead of energetic materials. These materials absorbs the impact energy and cause the bulging of steel plates.

2.3.2.4 Electromagnetic Reactive Armour

It passes an electric current through the incoming projectile to disrupt and destroy it.

2.3.3 Active Armours

Active armours make use of sensors to detect incoming threats and are designed to respond to intercept, disrupt or deflect these threats (Held, 1993).classifies different active defense concepts according intercept ranges as:

a) Close range <2 m

b) Medium range 2 to 10 m

c) Long range >10 m

The working principles of these three classes are introduced below (Held, 1993).

a) Sensors fire a small number of shaped charges to initiate the high explosive content of an attacking shaped charge warhead. Such an initiation prevents good jet formation. Sensors trigger impactors to destroy or disrupt incoming penetrator such that its broken pieces will hit a larger area on the armour with having less penetrative capability.

b) Sensors discriminate the direction, velocity and distance of a threat and fire a suitable fragmenting charge from an array. The fragments hit the incoming projectile and destroy it.

c) Sensors launch a highly maneuverable mini missile with active or semi-active homing head.

2.4 Related Research Work

Colombo *et al.* (2006) worked on ceramic polymer composite as a ballistic protection material and the sintered ceramic was procured from commercial industry and they came up with the result that the composite consisting of SiC foams and thermosetting (cross- linked) PU demonstrate a relatively high level of mechanical properties. He got the following result after carrying out the mechanical test on 98.5% alumina (see table 2.7). Armour systems based on only 6mm armour tiles bonded with SiC thermosetting PU composite backing could stop 5.56 x 45mm SS 109 and 7.62 x 51mm NATO ball FMJ projectiles, so these systems have potential for ballistic and blast protection for vehicular and structural application.

Table 2.7 Mechanical result of composite containing 98.5% alumina

Density	3.82-3.84 kg/m^3
Open porosity	<0.1%
Vickers hardness	12.9-13.7GPa
Fracture toughness	3.0-3.3 $MPa/m^{1/2}$
Young's modulus	330-400 GPa
Flexural Strength	260-280MPa

Source: Colombo *et al.* (2006).

Silva *et al.* (2014) worked on the mechanical characterization and ballistic test of alumina based armour plates. Three composition (92, 96, and 99 wt% Al_2O_3) were tested for 10mm thick plates processed in an industrial plant. Samples were pressed at 110 MPa and sintered at 1600 °C for 6 hours. Relative density, Vickers hardness, and four point flexural strength measurements of samples after sintering were performed. Results showed that the strength values ranged from 210 to 300 MPa depending on the porosity, with lower standard deviation for the 92wt% Al_2O_3 sample plate (120 mm x 120 mm x 12 mm) of this composition were selected for ballistic testing according to AISI 1045, using a metallic plate as backing and witness plates in the case of penetration or deformation. Standard NIJ-0108.01 was followed in regard to the type of projectile to be used (7.62 x 51AP, Level IV, 4068J). Five alumina plates were used in the ballistic tests (one shot per plate). None of the five shots penetrated or even deformed the metal sheet, showing that the composite containing 92wt% could be considered to be a potential ballistic ceramic, being able to withstand impacts with more than 4000 J of kinetic energy.

Chen *et al.* (2007) carried out investigation on the ballistic resistance capability of ceramic and Kevlar composite materials by using Taguchi method. Orthogonal array is adopted to organize the experiment, and then signal to noise ratio (S/N) analysis is used to realize the controllable factors effect to ballistic resistance. The contribution of each controllable factor is estimated by variance analysis (ANOVA).

The controllable factors considered in this paper include thickness ratio of ceramic to Kevlar, size of ceramic, and proportion of Z_rO_2 added. Each factor consists two levels, therefore L8 (2^3) of orthogonal array is chosen to build 8 different level testing samples. Smaller-the-better characteristic is adopted because residue velocity is obtained from the test. Following the analysis procedure, the optimal combination of the chosen factors is then obtained. The study found that if Z_rO_2 is added too much it increase the glass phase and reduce the capability of being a ballistics material, for this research they compared the sample consisting of 5% Z_rO_2 and 95% Al_2O_3, 15% Z_rO_2 and 85% Al_2O_3, the thickness ratio is 2:1, the ceramic panel size is 10cm × 10cm. From their result they observed that sample consisting of 95% Al_2O_3 and 15% Z_rO_2 is more suitable for ballistic material compare to the one with high Z_rO_2.

Sujirote *et al.* (2007) carried out an experimental investigation on ballistic performance of alumina tiles as a function of weight limitation, threat level, backing material, and multi-hit performance. Using alumina hexagons with nominal area of 800mm^2, ranging from 2.5 to 10 mm in thickness, were assembled on metal mesh placing on top of an aramid fiber layer using a synthetic rubber based cement. The assemblies, approximately 20 x 20cm^2 in sized wrapped by a PE layer, were then back up by either a 1.5mm thick iron sheet, a 3mm thick alumina plate, a 5mm thick aramid-PU composite. The samples were impacted by 9mm or SS 109 ammunitions at impact speed of 420 and 920 Sm/s, respectively. Measurement from trauma sizes on a standard clay box could be explained by observations of debris patterns 'frozen' on the rear surface. Typically, more conoids occur with greater thickness and production of pulverized zone is a necessary condition for penetration resistance. Debris from high impact, sharp ammunition (SS 109) was finely comminuted and compacted at the locus of conoid coaxial cracks, whereas relatively larger chunks were evident from blunt ammunitions. Likewise, the backing materials with different impedance effects may induce tensile failure across the boundaries and significantly influenced on crack propagation and debris comminution process. Impact resistance at edges and joints were obviously dropped by crack pattern alteration, leading to absence of locus conoid cracks. Thus it is necessary to maintain the same ballistic performance at the edges as at the center tile impacts had the armour designed to withstand multiple hit.

Kannigar *et al.* *(2012)* carried out an investigation on armour composite consisting of 100 x 100 mm^2 commercial monolithic ceramic front tile; i.e sintered Al_2O_3, sintered SiC, or hot-pressed B_4C bonded with an S_2-glass reinforced polymer composite (GRPC) backing plate. The ballistic test was performed against 7.62 mm projectiles (M80 Ball) in the velocity range of 800-970 m/s. A linear correlation between the areal density of armour and the V_{50} results was illustrated. The V_{50} ballistic limit values for the Al_2O_3, SiC, and B_4C composite armours, calculated via U.S. Mil-std-662F, were found to be 913 m/s, 829 m/s, respectively. High-speed photographic images captured during ballistic testing revealed the transition from dwell to penetration by the 7.62 mm projectiles. The complete penetration of all the armour composites was found to have occurred in approximately 200 microseconds. Furthermore, the relationship between the volume of the cone crack and mechanical properties were examined. The fracture toughness values of Al_2O_3, SiC, and B_4C were 4, 4.6, and 2.9 respectively. The volume of the cone cracks formed on the ceramic front tile plates increased with an increase in the fracture toughness of the ceramic materials.

Mücahit (2004) carried out an investigation on development of dense ceramic tiles from mixtures of alumina powders with different particle size distributions (PSD). He used three different alumina which are Seydisehir Electrofilter-residue Alumina (SEA), Seydisehir Coarse Alumina (SKA) containing (98.5% Al_2O_3) and Superground Alumina (Alcoa CT3000SG) containing (99.76% Al_2O_3). In the production of the dense alumina tiles the amount of binder used (polyvinyl alcohol (PVA)) is in the range of 0.1 to 3 wt % and the dense ceramic tiles were produced by blending different proportions particle size of TiO2, SiO_2, Cr_2O_3, CaO, MgO and MnO were used in other to determine the effect on the dense alumina. The packing of binary (SEA-CT3000SG) and ternary (SKA-SEA-CT3000SG) blends were predicted by using the software, MXENTRYfi and MIX10fi. These software utilized the Dinger-Funk (DF) equation for predictions of packing. Prepared blends were uniaxial dry-pressed and sintered. Archimedes' method was used to measure the density and porosity of the pellets. All results showed that the blend contained 100% super-ground alumina powders (99.8 wt %) with 0.35- 0.45 μm particle size, surface area of 8-11m^2/g and achieved almost full density (98%) at 1550°C. In binary blends, if the proportion of SEA was up to 50%, porosity values of these blends increased. Also the effects of additives such as TiO_2 and MnO on densification and mechanical properties of pellets were investigated. The additives provided higher fired densities between 91 and 99%.

Vickers hardness tests were conducted to determine mechanical properties of the sintered pellets. The samples that contained relatively higher proportions of fine particles provided higher hardness values in a range of 1500 and 2100 kg.mm. Also, microstructural characterization of the pellets was done using SEM. Finally, the tiles at desired dimensions were produced based on the blends that give the highest density and hardness values, Porosity and density measurements, microstructural and mechanical characterizations of the tiles were carried out.

In conclusion super-ground alumina (Alcoa CT3000SG) particle size was smaller than 1 μm and that the particles were not as porous as the previous alumina powders. Eugene (2005) carried out research on alumina ceramics which were based on the system of Al_2O_3–SiO_2 with sintering aids selected from earth-alkali silicates or borosilicates (AM materials) and based on the system of Al2O3–SiO_2–ZrO_2 with sintering aids promoting mullite formation and ZrO_2 stabilizing (ZAS materials). The alumina as density values ranging from 3.5–3.75 g/cm^3 depending on composition and which is sintered bellow 1550°C. The alumina size used for the mechanical, microstructural test and ballistic test is 100 mm x 100 mm x (7–10) mm. In is research he observed that ceramics with two or more crystalline phases have a remarkable level of physical properties and low brittleness, and they may be used for armour and wear resistance applications. Alumina–mullite ceramics (e.g. AM2 composition) has a uniform microcrystalline structure and a low content of a glassy phase are the most promising for armour applications due to a high level of ballistic performance and lower density (3.52–3.56 g/cm^3 versus 3.8–3.9 g/cm^3 inherent to high alumina ceramics) and these ceramics also demonstrated the highest wear resistance among other studied materials.

He also observed that the presence of zirconia and residual zircon ingredients in the alumina– mullite ceramics (ZAS compositions) results in an increase of density, and, therefore, of weight of ceramic components. Although the ceramics with a relatively low content of zirconia and zircon (e.g. ZAS_2 material) demonstrated high mechanical properties and lower brittleness than the "two- phased" alumina–mullite ceramics, their ballistic performance and wear resistance were still lower. However, ZAS ceramics are less sensitive to thermal stresses.

Galvez *et al.* (n.d) carried out an investigation on tensile strength of ceramic materials at high rates of strain. They procured sintered ceramic of 99.5% Al_2O_3, 94% Al_2O_3 and SiC. The specimen geometry used in the Brazilian tests was a disc of 4mm height and 8mm in diameter while in spalling test bar of 8mm in diameter and 100mm long were used. They observed that SiC behave quite different from Al_2O_3 from what they saw in the high speed photogram, in the alumina (99.5% and 94% Al_2O_3) the failure zone is so localized instead of the wide zone that is in the SiC. SiC failed at very short time and very low tension stress.

Roy *et al.* (2011) carried out a research on advanced layered personnel armour. They used different layers in order to optimize the role of each layer during the projectile defect. The first layer is very hard in order to be able to deform and fracture the projectile, an orthotropic second layer to slow down the shock wave propagation, third layer to absorb the shock wave energy and the forth layer to provide confinement for the porous medium. The materials used are alumina (6mm thick of 98% Al_2O_3 with a density of 3.81g/cm^3) dyneema®HB25 (5mm thick with density of 0.97g/cm^3) procured from DSM and porous polyurethane (PU) foam (4.76mm thick of AISI 4140 Steel with a density of 7.85g/cm^3) procured from botossi Industry.

They observed that the composite is more effective in resisting penetration than a high strength steel plate equivalent and they also notice that ceramic and dyneema composite plate of lower area density outperformed that of the AISI 4140 armour steel.

Badmos *et al.* (2001). Carried out an investigation on characterization of structural alumina ceramics used in ballistic armour and wear applications. They used sintered ceramic which contain 0.2-0.5wt% MgO and 98% Al_2O_3 with particle size of 3μm. They observed that the ceramic that is been formed through dry pressing method has a higher hardness compare to slip casting. They also observed that the presence of MgO and CaO play a principal role in sintered alumina.

CHAPTER THREE

3.0 Materials and Methods

3.1 Materials

The major materials required for this investigation are:

i. Alumina (Al_2O_3) powder

ii. Additives (Magnesium oxide and Calcium oxide)

iii. Binders (Polyvinyl alcohol)

3.2 Equipment

The major equipment used for this work include:

i. Mould

ii. Pressing Machine (110MPa)

iii. Furnace (1600°C)

iv. Hardness testing machine (HTM)

v. Mortar and pestle

vi. Microstructural testing machine

vii. Electronics balance

3.3 Experimental Procedures

3.3.1 Materials Selection

This study required magnesium oxide (MgO), calcium oxide (CaO), high purity powdered alumina (Al_2O_3) and polyvinyl alcohol (PVA). Alumina powder was the major material used for the research, produced by SH Chemical Group Limited, China. Magnesium oxide (MgO) and calcium oxide (CaO), served as hardening additive and grain stabilizer to the powdered alumina respectively, produced by Konoshima Chemicals Company Limited, Japan. The polyvinyl alcohol (PVA) served as a binding agent was also produced by Konoshima Chemical Company, Japan. The chemical analysis of 99.99% Al_2O_3 as provided by the Manufacturer is shown in Table 3.1.

Table 3.1 Chemical analysis of as-received Alumina

Product Name:	Alumina Oxide		**Manufacture Date:**	2015-08-15
Batch Number:	150815		**Analysis Date:**	2015-0816
Batch Quantity :		1000KGS		
ITEM		**SPECIFICATION**	**DETECTION**	
Appearance		White solid powder	White solid powder	
Al_2O_3		99.999% Min.	99.999%	
PH value		6-8	6.6	
Si		5ppm Max.	2ppm	
Fe		3ppm Max.	2ppm	
Na		2ppm Max.	1ppm	
Ca		2ppm Max.	1ppm	
Mg		2ppm Max.	1ppm	
Ti		1ppm Max.	Conform	
Zr		1ppm Max.	Conform	
Particle size D50		0.2-5μm	Conform	

Source: SH Chemical Limited, China

The materials formulation adopted for this research is shown in table 3.2 and it bar chart is shown in figure 3.1

Table 3.2: Materials formulation weight percentage

Component				
Designation	Al_2O_3 (%Wt)	CaO (%Wt)	MgO (%Wt)	PVA (%Wt)
A	97.2	2.3	0.5	0
B	96.2	2.3	0.5	1
C	95.2	2.3	0.5	2
D	94.2	2.3	0.5	3
E	93.2	2.3	0.5	4
F	92.2	2.3	0.5	5

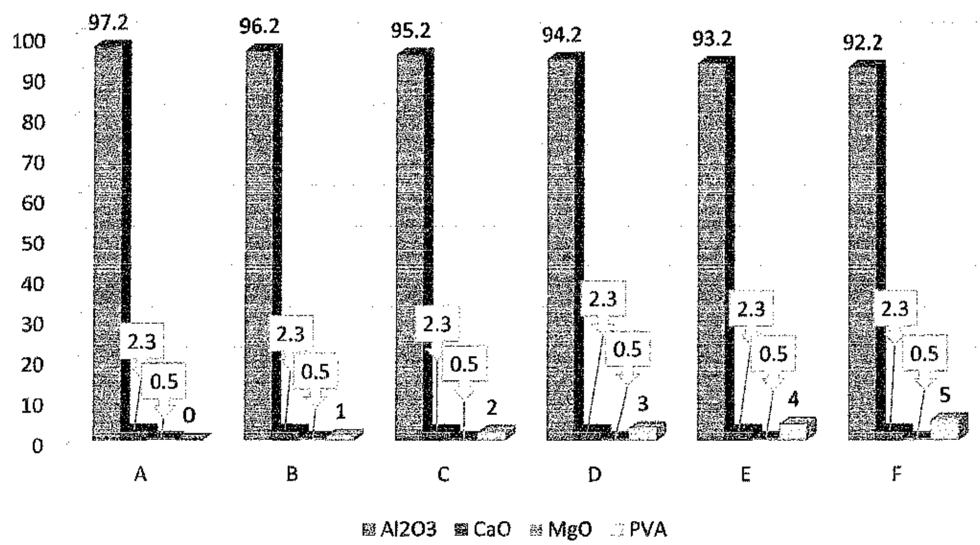

Figure 3.1: Materials formulation weight percentage

After the appropriate formulation, the materials were mixed thoroughly in the mortar with pestle in order to avoid significant density gradients and textures in the green body, which can be amplified during sintering, leading to distortions and internal mechanical stresses (Breviary, n.d). The mortar and pestle used is shown in see plate 3.1.

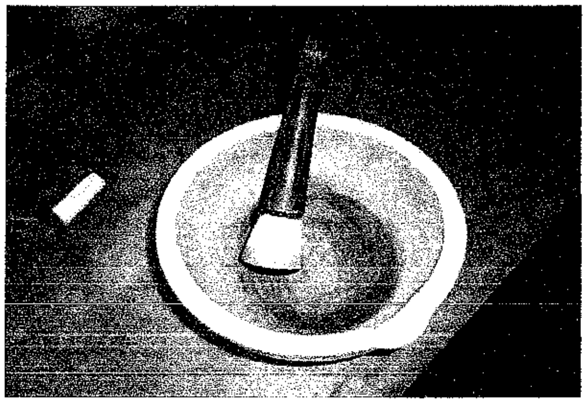

Plate 3.1: Mortar and pestle

3.3.2 Mould Fabrication

The moulds which was used for forming process after the materials has been mixed properly was fabricated to the size of 100mm x 50mm x 30mm and 50mm x 50mm x 30mm, using mild steel material, plate 3.2 shows the fabricated mould and the details drawing in figure 3.2.

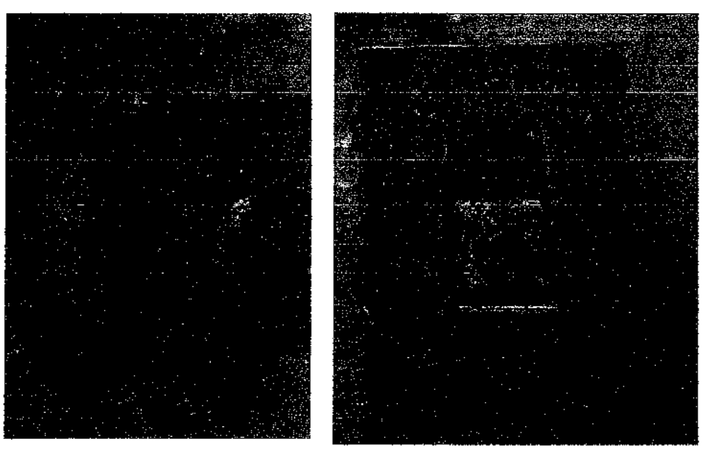

Plate 3.2: Mould

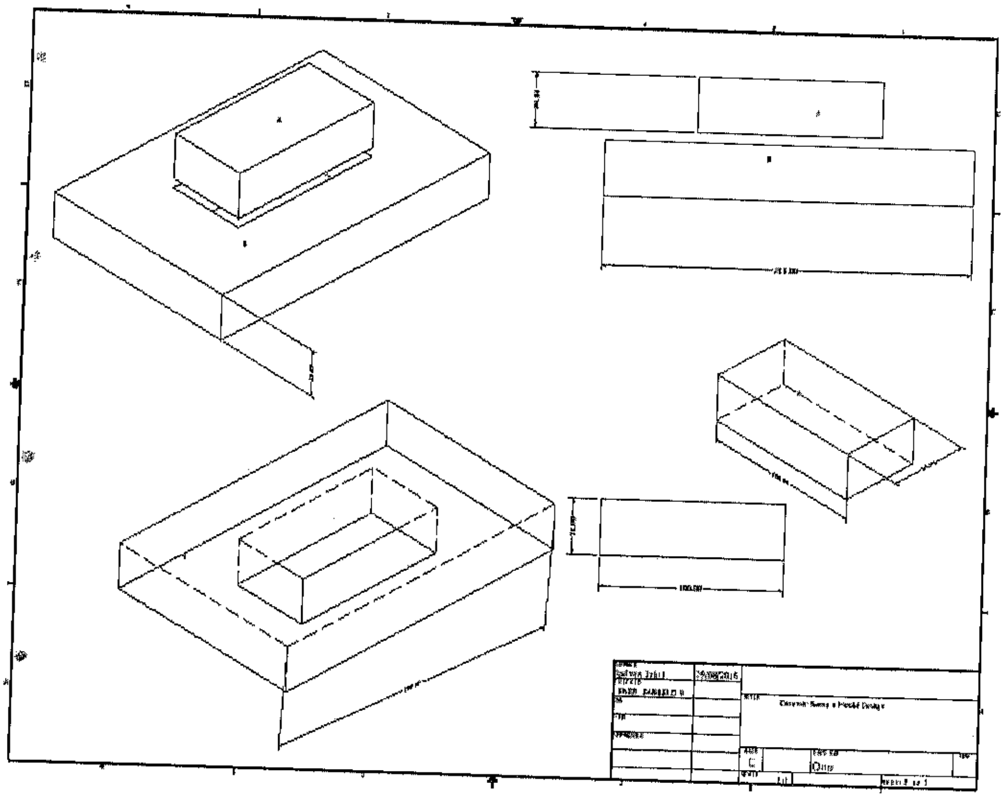

Figure 3.2: mould isometric view

In ceramic production Specific preparations of unfired material are required for the different forming processes such as slip for casting, granulates for pressing and plastic material for extrusion, but for this research dry pressing method was adopted. The formulated non-clumping granulates was compressed under a pressure of 300KN (Breviary, n.d, Silva *et al.* 2014, Kannigar *et al.* 2012) in the designed steel mould. The powder particles was compacted to form a coherent shape with sufficient strength for subsequent handling. The pressing machine used was Paul Weber with model number D-7064 and which has the maximum capacity of 350KN. It is available in Nigeria Metallurgical Development Center (NMDC), Jos, Nigeria. Plate

3.3 shows the pressed samples with inscription A-F as designated in the formulation table 3.2.

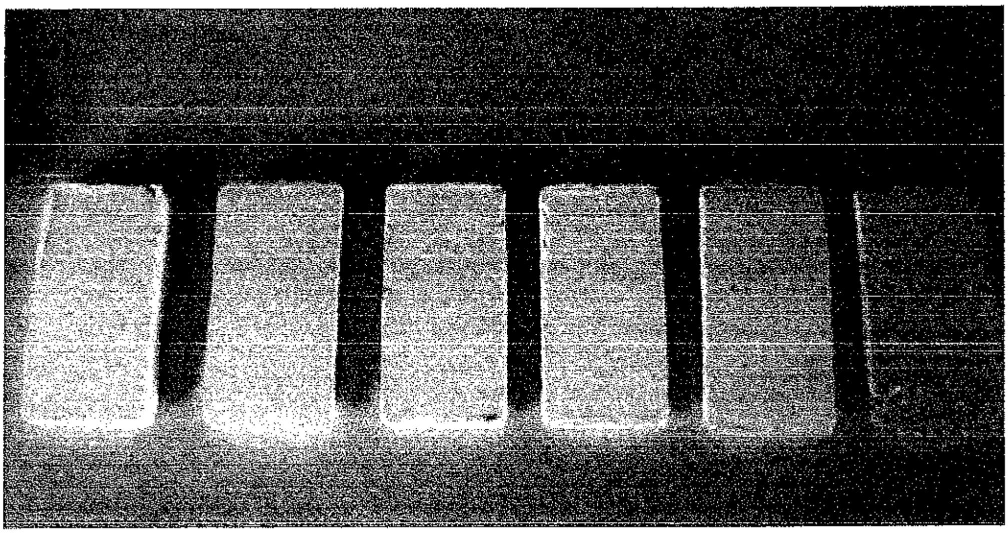

Plate 3.3: pressed ceramics

3.3.3 Sintering

The green body made by the forming process through pressing method contains addition of moisture, organic deflocculants, binder, etc. The green body was sintered to 1500°C (Mücahit, 2004; Eugene, 2005) at the heating rate of 25°C /min in a CARBOLITE electric Furnace (serial number 8/01/1953, model number RHF 16/15 and maximum temperature capacity of 1600 °C; England) available at NMDC, Jos-Nigeria. The green body was soaked for an hour. Plate 3.4 shows the electric furnace used.

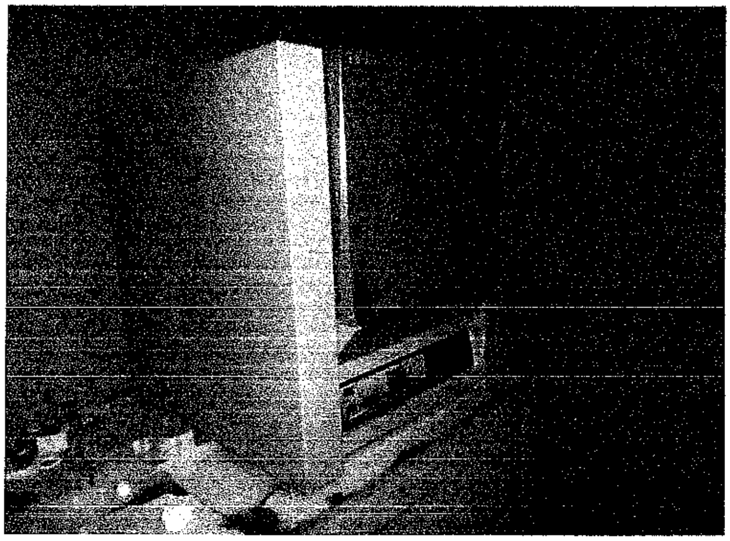

Plate 3.4: Electric furnace

The below flow chart, figure 3.3, is the summary of the ceramic production process routes

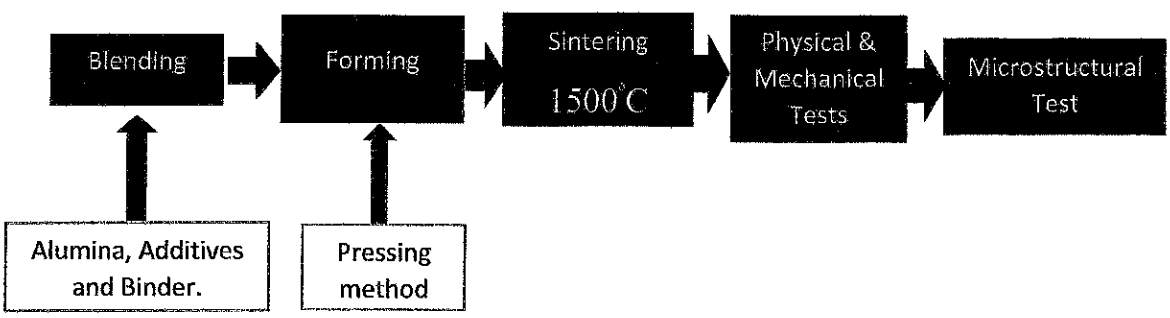

Figure 3.3: Processing steps involved in making ceramic parts

3.4 Physical Properties Tests

Physical tests were carried out on the produced sintered ceramic samples; such as porosity, density, weight and shrinkage percentage.

3.4.1 Density and Porosity

Material density in structural ceramics is important. The higher the porosity is, the less the mechanical performance is (Javier, 2007). For the experimental density measurement, dimensional method (M/V) and Archimedes method were adopted according to ASTM-B311 (2013) standard. Fundamental assumptions which was made is that the test specimens are not attacked by water, the test specimens conform to the requirements for size, configuration, and original faces, the open pores of the test specimens are fully impregnated with water during the boiling treatment, Density and porosity test was conducted with an electronics balance (Model number XY300C with Serial number 14092192, maximum weight 3100g with readability of 0.01g and available at Faculty of Agriculture Laboratory, Federal University Oye-Ekiti). Plate 3.5 shows the electronics balance. Deviation from any of these assumptions adversely affects the test results.

Archimedes immersion technique

Archimedes Principle states that the buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object (Berger *et al.* 2010).

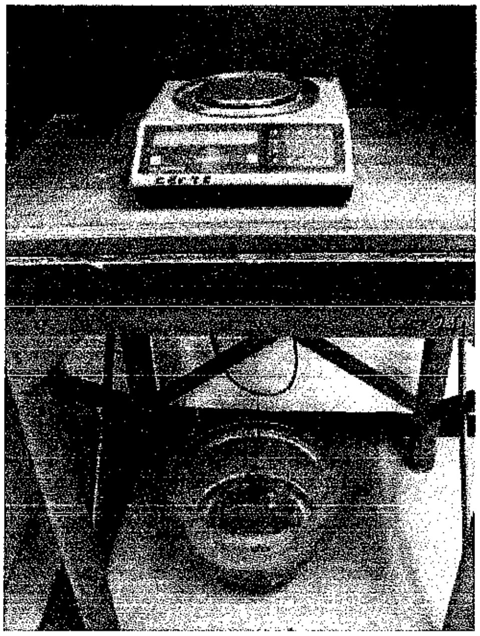

Plate 3.5: Determination of Density using Archimedes principle

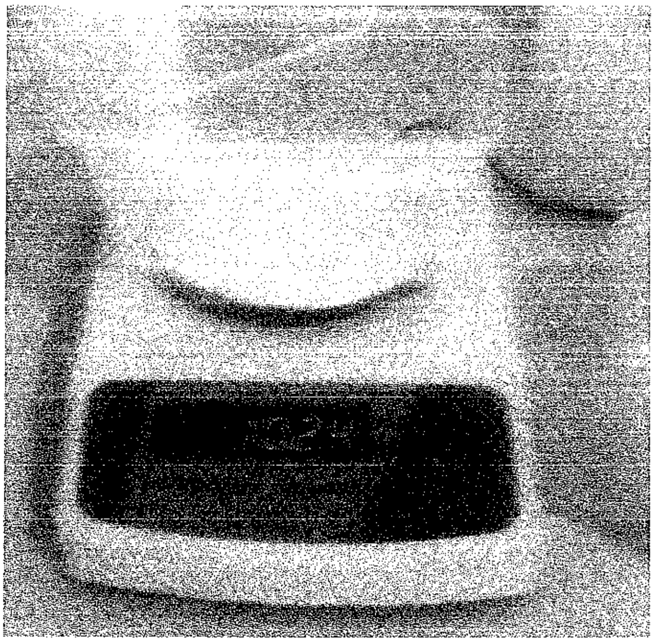

Plate 3.6: electronics balance used for porosity and water absorption

3.5 Mechanical test of the samples

After the ceramic plate has been sintered, the following mechanical test was carried out on it, which determines the mechanical properties of the products and compare it with the existing mechanical properties of a ballistic material.

i. Hardness Test (ASTM- C1326 and C1327)

ii. Young's Modulus Test (ASTM-C848)

iii. Compressive Strength Test (ASTM-C773)

3.5.1 Hardness Test

This test method covers the determination of the Vickers indentation hardness of advanced ceramics. In this test, a pointed, squared base, pyramidal diamond indenter of prescribed shape was pressed into the surface of the ceramic with a predetermined force (100N) to produce a relative small, permanent indentation according to ASTM-C1326 and C1327 (2015) standards. Vickers hardness testing machine which was used to carry out the test on the produced sintered ceramic samples was Computerized Vickers Hardness Tester with model number VM-50 PC and which has the maximum capacity of 350KN and available in Nigeria Metallurgical Development Center (NMDC), Jos, Nigeria. The surface projection of the two diagonals of the permanent indentation was measured using a light microscope. The average diagonal size and the applied force are used to calculate the Vickers hardness, which represents the material's resistance to penetration by the Vickers indenter, plate 3.7 shows the Vickers hardness testing machine used. Hardness was computed as the ratio of the force to the contact surface area and Vickers hardness of alumina ceramics samples was calculated according to equation 1 (Badmos *et al.*, 2001).

$$H_v = 1.8544\frac{P}{d^2} \text{ or } H_v = 0.1891\frac{F}{d^2} \quad \text{.......................................(1)}$$

Where:

H_v = Vickers hardness,

P = applied load in (kg)

F = applied load (N),

d = arithmetic mean of the two diagonal length (mm).

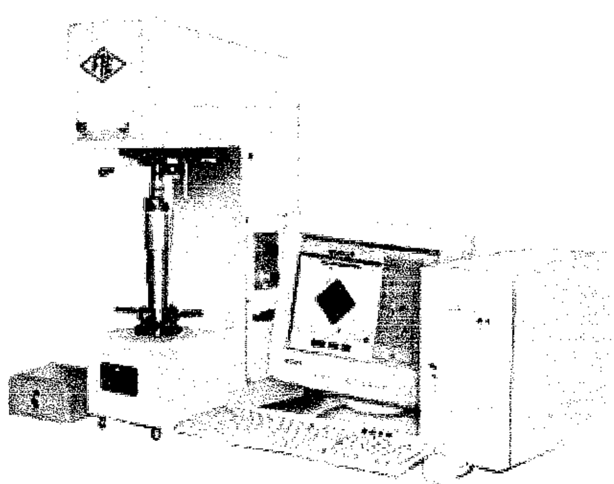

Plate 3.7: Hardness Testing Machine

3.5.2 Young's Modulus Test

This test method covers the determination of the elastic properties of ceramic samples. Specimens of these materials possess specific mechanical resonance frequencies which are defined by the elastic modulus, density, and geometry of the test specimen. Therefore the elastic properties of the produced sintered ceramic samples was computed with their geometry, density, and mechanical resonance frequencies according to ASTM-C848 (2016), standard. Young's modulus was determined using the resonance frequency in the flexural mode of vibration.

3.5.3 Compressive Test

Resistance to compression is the measure of the greatest strength of a ceramic material (ref); ceramics should be stressed as such in use. This test is a measure of the potential load-bearing usefulness of a ceramic. In order to measure the compressive strength of the produced sintered ceramic samples, ASTM-C773 (2016) standard was adopted.

3.6 Microstructural Test

Microstructural analysis was carried out using scanning electronics microscope (SEM) and micro-chemical analysis was performed using energy dispersive X-ray (EDX) spectroscopy in the SEM. Material for microstructural characterization used was prepared as for normal metallographic studies. A Phenom proX SEM with model number 800-07334 and part number MVE02246651193, equipped with an energy dispersive X-ray (EDX) detector was used for the microstructural and composition analysis of the sample; available in Covenant University, Faculty of Technology, Mechanical Department, Ota, Ogun State. Plate 3.8 shows the scanning electron microscopy used.

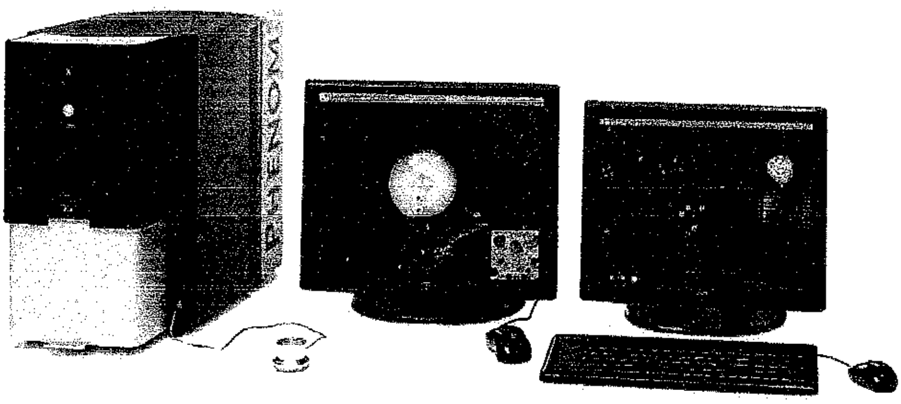

Plate 3.8: Scanning electron microscope

Chapter Four

4.0 Results and Discussion

4.1 Physical properties of the samples

The results of physical properties of the sintered ceramic samples showed that sample A had the highest shrinkage value and density among the other samples; see Table 4.1. The shrinkage and density value of sample A, may be due to the absence of binder or the temperature at which it being sintered is not enough. Sample A had a low value in weight when compared to sample B and this may be attributed to the absence of binder as it was observed that there was a little reduction in the weight after sintering and as the binder was added the weight and density reduced drastically after sintering (Table 4.1).

However, at one percent binder sample, a reverse case was observed as opposed what was observed in sample A and this may be due to low binder in that sample or ratio in which the binder, alumina powder and additives were mixed together (Table 4.1). Sample B weight after sintering was greater than sample A weight value, but it density was lower than sample A and percentage of shrinkage value was minimal when compared to sample A (Table 4.1). Sample C and D had low weight and less shrinkage when compared to sample A and B, but there was no significant difference in their density (Table 4.1). It can therefore be deduced that the influence of binder and formulation ratio of the components was not too significant. The difference between sample E and F physical properties was not significant, but sample E had the lowest weight value among the six samples, while sample F had the lowest percentage shrinkage among the six samples. After the physical properties of the samples have been studied, it was discovered that sample B and sample E had the best physical properties among the six samples. Comparing the density of the two samples with the established density of ceramic plate used for body amour application, it was clear that the two samples had lower densities than the previous findings of Galvez *et al.,* Tolochko (2011), Fawaz *et al.*, (2004) and Medvedovski (2006). This indicates that a new less dense ceramic has been produced (Table 4.1). However, after the physical properties of the sample has been measured, the relationship of the two samples with regards to their densities was established (Figure 4.2). The density reduced as percentage weight of binder increased as this is an indication that in sintering process, binder has a viable role to play in the sintered alumina ceramics density (Figure 4.2). The effect of binder on the six samples was significant and appropriate formulation is very important in advanced ceramic production.

For the porosity, sample B had the lowest porosity of (0.015) and low water absorption while sample F had the highest porosity of (0.035) as well as high water absorption (Table 4.2)

Table 4.1: Physical properties of the sintered samples

Designation	Initial Length (cm)	Final Length (cm)	Initial Weight (g)	Final Weight (g)	Density ρ (g/cm^3)
A	10	8.5	100	90.02	3.69
B	10	8.7	100	92.78	3.53
C	10	8.6	100	87.67	3.51
D	10	8.5	100	86.40	3.51
E	10	8.6	100	84.00	3.48
F	10	8.8	100	84.48	3.45

Table 4.2: porosity and water absorption result of the six samples

Designation	Porosity	Water absorption
A	0.03	9.90
B	0.015	7.85
C	0.05	10.82
D	0.04	10.40
E	0.02	8.25
F	0.035	9.96

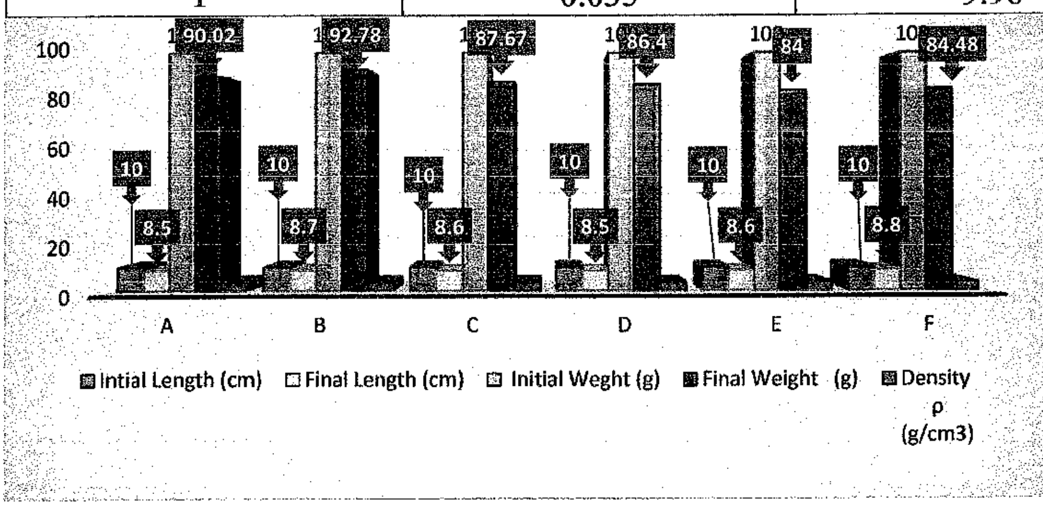

Figure 4.1: Physical properties of the sintered samples

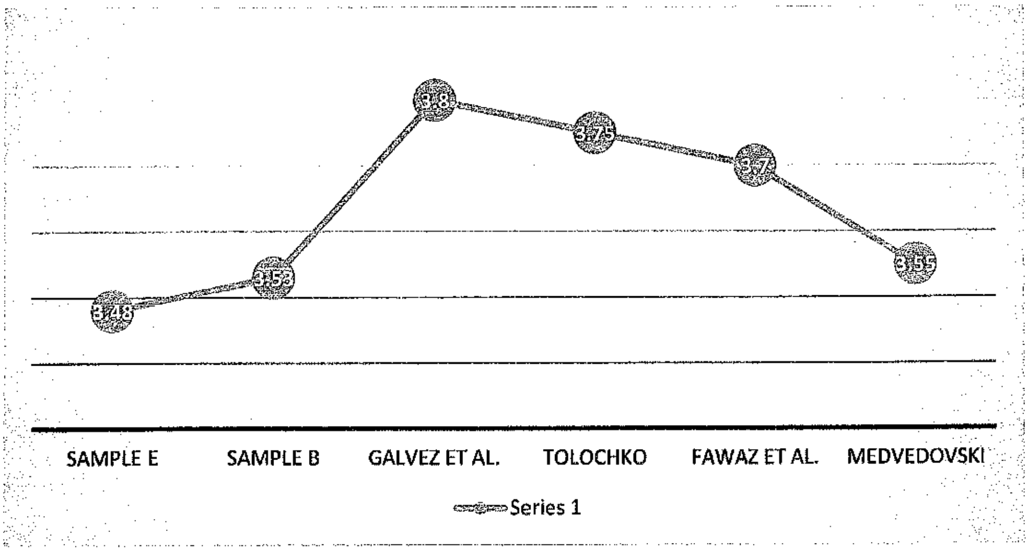

Figure 4.2: New samples density in relation to established ceramic density

4.2 Mechanical properties of the sintered ceramic samples

The results measurements of mechanical properties of the sintered samples were shown in table 4.3.

Mechanical test was carried out on the six samples in order determine samples that can meet the standard mechanical properties of a sintered ceramic used for body amour application. With regards to the values of hardness, modulus of elasticity and compressive strength for the studied composition, sample F had the lowest elastic modulus in comparison with sample A, B, C, D and E (Table 4.3). For a technical application sample F cannot be used according to (Kanno, 2009).

The mechanical results showed that, sample A has hardness value of (11.2 GPa), which was the highest hardness value recorded amongst the six samples, but has (243 GPa) as modulus of elasticity value and (2208 MPa) as compressive strength value (Table 4.3).

However, sample A had shown low value in modulus of elasticity and compressive strength among the six samples and comparing it with the established modulus of elasticity and hardness value of Fawaz *et al.*, (2004). Although, higher than the value got by Medvedovski (2006). Sample B had hardness value of (10.4 GPa) with modulus of elasticity value of (248 GPa) and compressive value of (2454 MPa) (Table 4.3). Sample B had the highest value in modulus of elasticity and compressive strength among the six sintered ceramic samples produced. By comparing sample B hardness and modulus of elasticity results with the established result of silva *et al.*, (2014), sample B had low hardness value with high modulus of elasticity and has higher value when compared with the established result of Badmos *et al.*, (2001) and Medvedovski (2006). Sample C and Sample D mechanical results showed low values in compressive strength and modulus of elasticity while their hardness values were (10.8Gpa) and (11.0GPa) respectively (Table 4.3). The dry pressed sample with four percent binder had the lowest hardness value with elastic modulus of (279GPa). The sample which contained one percent binder had the highest elastic modulus which indicated that as the binder increased in percentage weight in its total composition, it reduced the hardness and increased the modulus of elasticity.

Designation	Hardness H_v (GPa)	Elastic Modulus E (GPa)	Compressive Strength (MPa)
A	11.2	243	2208
B	10.4	284	2454
C	10.8	263	2302
D	11.0	238	2201
E	10.1	279	2454
F	10.6	221	2401

Table 4.3: Mechanical properties of the sintered samples

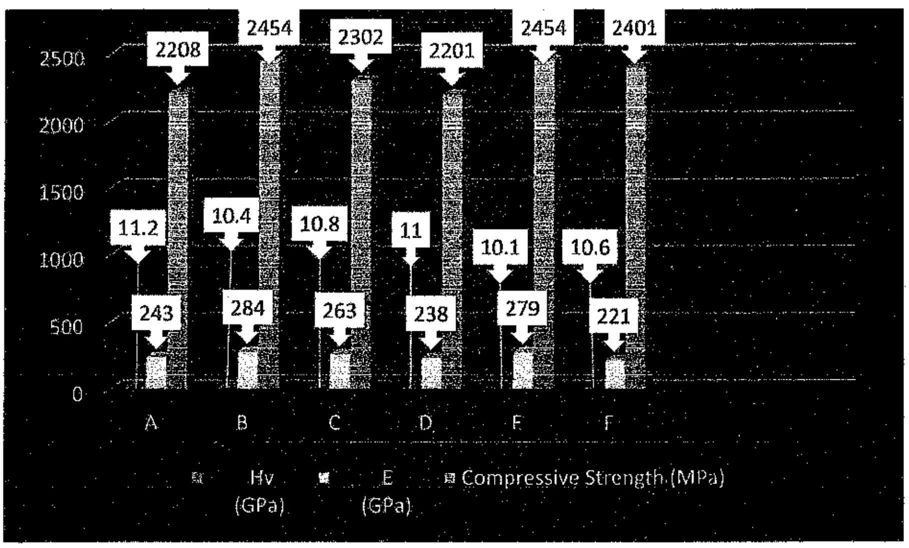

Figure 4.3: Mechanical properties of the sintered sample

4.3 Microstructure of the selected sample

Due to the trend of the mechanical results of the six sintered ceramic samples, Sample B microstructure was studied. Scanning electron microscopy (SEM) image and energy dispersive X-ray (EDX) analysis of sample is shown in figure 4.3 and figure 4.4 respectively.

The microstructure of the tested sample showed that, the sample had a uniform solid distribution within themselves, and this may be due to the thorough mixture of the formulation at the forming process stage. The result showed that the uniform solids were in section, which could be due to isostatic single point load or the force applied was not up to the required force (Figure 4.3). From the image viewed, it was observed that pores were present in the sample tested but minimal. The presence of pores in the sample might have been due to the force applied during forming process.

Figure 4.4: sample B SEM image

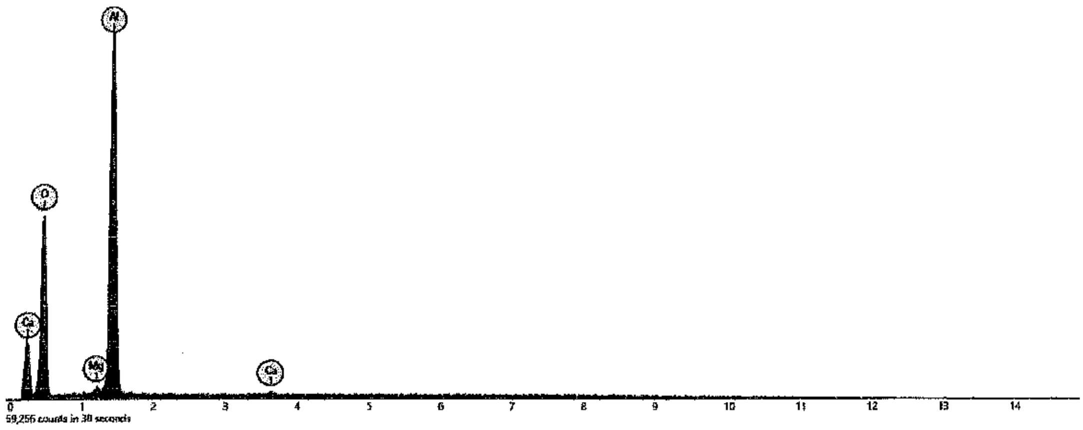

Figure 4.5: EDX of the selected sample

Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
13	Al	Aluminium	100.0	41.0	0.8
8	O	Oxygen	100.0	56.9	1.2
12	Mg	Magnesium	Manual	1.2	6.7
20	Ca	Calcium	Manual	0.9	8.5

CHAPTER FIVE

5.0 Conclusion and Recommendation

5.1 Conclusion

Six different formulations of ceramic plates were produced by varying it powered alumina percentage weight and binding agent polyvinyl alcohol. They were sintered at 1500°C and were investigated in this work in order to be used for body armour application. The six sintered ceramic samples were characterized by density, porosity water absorption, Vickers hardness, compressive strength and modulus of elasticity. The results obtained reliability was evaluated by comparing it with the established and standard results. According to the obtained results, sample B was selected as a plate that has the potential properties of body armour material, although sample B and sample E had similar results with each other.

Hence, sample B was chosen based on low porosity, high hardness and high modulus of elasticity.

5.2 Recommendation for further research work

This research work recommends sample B with regards to its low porosity, high hardness and high modulus of elasticity. Although, further investigation may be carried out in the following areas; flexural strength, Weibull modulus and ballistic test in order to ascertain its properties according to standard ceramic armour application.

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