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# DETERMINATION OF SUITABLE LOCALLY PRODUCED STEEL IN NIGERIA AS A BASE MATERIAL FOR THE PRODUCTION OF HIGH IMPACT RESITING PANEL MATERIAL

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## Abstract

The Armoured Tank Panel (ATP) of the Main Battle Tank (MBT) and two steel products produced in Nigeria, the Nigerian Steel 65 Manganese (NST 65 Mn) and Nigeria-Spanish Steel rods (SS Steel) were studied with a view of using the better of the two steel products as the base material for the production of High Impact resisting Material in Nigeria. The chemical analysis of the ATP, NST 65 Mn steel and SS steel was carried out using the Minipal 4 energy dispersive X-ray fluorescence (EDXRF) spectrometer according to ASTM E572-02a (2006) e2. The results of the chemical analysis carried out to characterize the materials revealed that the ATP has total alloy content of 5.356%, NST 65 Mn steel has 2.2% and SS steel has 2.51% total alloy content and the rest is Iron. Rockwell hardness test on B - Scale according to ASTM A370, ASTM E10 and ASTM E18 standard was carried out and averages taken. The ATP was averaged at 117 HRB, NST 65 Mn steel 84.8 HRB and SS steel was averaged at 83.5 HRB. The impact test was carried out using ASTM E23 standards, for Charpy 45$^{o}$ V- notch. The results of the tests were also averaged with ATP averaged at 109 Joules, NST 65 Mn steel 70 Joules and SS steel 67 Joules. These results showed that the ATP had better mechanical properties than both the NST 65 Mn steel and SS steel. It also revealed that NST 65 Mn steel has better mechanical properties than SS steel and therefore the best choice as base material for the production of armoured tank panel from locally sourced materials in Nigeria.

**Key words:** Armoured Tank Panel, X-Ray Fluorescence Spectrometer, Rockwell Hardness Test, Impact Test, Nigerian Steel 65 Mn, Nigeria-Spanish Steel.

## 1. Introduction

The Armoured Tank Panel (ATP) of the Main Battle Tank (MBT) and two steel products, the Nigerian Steel 65 Manganese (NST 65 Mn) produced by Zuma Steel Ltd Jos, Nigeria (formerly Jos Steel Rolling Company) and Nigeria-Spanish Steel rods (SS Steel) produced by Nigeria-Spanish Steel Kano, Nigeria were studied with a view of using the best of the two steel products as a base material for the production of High impact resisting panel material in Nigeria. The level of protection offered by the armoured tank to its crew (the commander, the driver, the gunner and the loader) depends on the properties of the material the tank panel is made of. The Defence Industries Corporation of Nigeria (DICON) in its drive towards established roles of producing armaments for the country is embarking on improvisation, design and development.

To achieve this objective, a lot of research is required on development of available materials, design and production. Hence, Nigeria endowed with huge deposits of iron ore, the Ajaokuta Steel Company, The Delta Steel Company, three Inland Rolling mills, the Defence Industries Corporation and other privately owned steel mills is well placed to develop materials for its needs.

Most material selection for the manufacture of engineering parts involves some form of compromise. Each material offers a different blend of workability, hardness, yield strength, thermal conductivity, thickness, rust corrosion resistance, cost and method of manufacture amongst others.

The designer's need to select an ideal armour material is guided by several factors. The major consideration was for the armour material to be effective in offering protection to the crew and to resist enemy weapons. It must be effective, light and provide a variety of advantages for secondary effects and the material should be cost effective Masianca, (2004). Montgomery and Chin (2004) stated that an important requirement for the armour material is that it should be amenable to modern construction techniques, readily weld-able and capable of being produced in variety of shapes. Ryan, (1995); Farah and leeming, (1997) stated that material for armoured tank should provide protection to the crew and the tank. Bulkiness was also reported in Dda (2003) as an important factor. Steel armour was reported as comprising the past, present and future armour materials, and that it is easily field repairable and has good degradation resistance against ambient environment, Holloman et al (1997); Holloman and Jaffe (1999). Steel is inherently inexpensive due to its low material and fabrication cost, as well as the commercial steel production capacity and is readily available in Nigeria. It was also reported to offer good ballistics protection from a wide spectrum of threats with multi-hit capability and can be easily cut, machined, formed and welded. It was found that steel at maximum hardness, but enough toughness can resist cracking in all situations and provide the best ballistics performance Holloman et al (1997).

Kolthoff et al (1999) stated that the physical and chemical properties of ferrous material are determined by the types and amounts of minor or subsidiary elements present and that steel analysis constitute the quantitative determination of the elements present and iron itself is rarely determined. Steel analysis therefore is important in the determination of the suitability of the material for armoured application.

## 2.0 Determination of Chemical Composition of ATP, NST 65 Mn and SS Steel

The chemical analysis of the ATP, NST 65 Mn steel and SS steel was carried out using the Minipal 4 energy dispersive X-ray fluorescence (EDXRF) spectrometer by Panalytical BV, Netherlands according to ASTM E572-02a (2006) e2 standard test methods for analysis of stainless and alloy steels. Metal chips from the different materials were produced, washed with distilled water and heated in an oven to a temperature 105$^{o}$C for one hour and allowed to cool in air then inserted into the Minipal 4 EDXRF X-Ray spectrometer for elemental determination.

## 3.0 Determination of Hardness and Impact Strength of ATP, NST 65 Mn Steel and SS Steel

### 3.1 Hardness Test

Materials for armour must be checked for hardness as a survivability requirement. Steel for armour plates must be strong, hard and tough, Amptiac Quarterly, vol. 8 (2004). Edward and Mathewson, (1997) reported that hardness is one of the most important requirements of the armoured material. Rockwell and Brinell hardness tests have been used to test hardness of armoured material. Both Charpy and Pellini drop weight impact tests were reported to have been used by Naval research laboratory, USA as a qualitative test to measure crack arrest and are widely used today for structural materials, Kalpakjan, (1991); American Society of Metals, (1988). In this research the Rockwell hardness on test B - Scale using 10 mm diameter steel ball according to ASTM A370, ASTM E10 and ASTM E18 standard was used. Rockwell hardness testing machine by Karl Franck GMBH, Germany model 38506 was used.

### 3.2 Impact test

Impact test was carried out using ASTM E23 standard test method using standard dimensions for rectangular bar for Charpy 45$^{o}$ V- notch. The equipment used for the tests was Avery Denison impact testing machine model 6705U/33716 with impact velocity of 5.2 m/s.

## 4.0 Results

Table 4.1 shows results of chemical analysis of the ATP, NST 65Mn steel and SS steel carried out using Minipal 4 EDXRF spectrometer. Table 4.2 shows results of hardness test carried out on the materials according to ASTM A370, ASTM E10 and ASTM E18 using standard equipment and table 4.3 shows results of impact test carried out according to ASTM E23 standard test method for Charpy 45$^{o}$ V- Notch for rectangular bars.

**Table 4.1: Results of Chemical analysis of ATP, NST 65Mn steel and SS steel**

| Materials | Chemical composition % | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Fe** | **C** | **Mn** | **Cr** | **Ni** | **V** | **Si** | **P** | **S** | **Cu** | **Mo** | **B** |
| Armoured Tank Panel | 94.64 | 0.32 | 1.20 | 1.00 | 0.30 | - | 1.80 | 0.015 | 0.016 | - | 0.70 | 0.005 |
| NST 65 Mn Steel | 97.78 | 0.30 | 1.04 | 0.01 | 0.01 | 0.10 | 0.02 | 0.005 | 0.015 | 0.02 | 0.70 | - |
| Spanish steel | 97.49 | 0.30 | 0.53 | 0.12 | 0.12 | - | 0.21 | 0.01 | 0.30 | 0.22 | 0.70 | - |

**Table 4.2: Results of Rockwell Hardness test on ATP, NST 65 Mn steel and SS steel**

| **Materials** | **Load** | | **Scale** | **Test Block Number** | **Indenter Diameter** | **HRB Value** | **HRB Value** | **HRB Value** | **Average HRB Value** |
|---|---|---|---|---|---|---|---|---|---|
| | **Minor (N)** | **Major(N)** | | | | **Test 1** | **Test 2** | **Test 3** | |
| **Armoured Tank Panel** | **98** | **980** | **B-Scale** | **101.2 HRB Plate** | **1.6mm Steel Ball** | **111** | **118** | **122** | **117** |
| **NST 65 Mn Steel** | **98** | **980** | **B-Scale** | **101.2 HRB Plate** | **1.6mm Steel Ball** | **85** | **84.8** | **85** | **84.8** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Spanish Steel** | **98** | **980** | **B-Scale** | **101.2 HRB Plate** | **1.6mm Steel Ball** | **83.5** | **83.5** | **84** | **83.5** |

**Table 4.3 : Results of Charpy 45° V-Notch impact test of ATP, NST 65Mn steel and SS Steel**

| Material | Impact Velocity m/s | Energy AbsorbedJ Test 1 | Energy AbsorbedJ Test 2 | Energy Absorbed J Test 3 | Average Energy Absorbed J | Type of Specimen |
|---|---|---|---|---|---|---|
| **Armoured tank Panel** | **5.24** | **108** | **109** | **110** | **109** | **Std Rectangular** |
| **NST 65 Mn Steel** | **5.24** | **72** | **71** | **68** | **70** | **Std Rectangular** |
| **Spanish Steel** | **5.24** | **68** | **66** | **67** | **67** | **Std Rectangular** |

## 5.0 Discussion of Results

The results of the chemical analysis carried out to characterize the armoured tank panel, NST 65 Mn steel; SS steel presented in table 4.1 revealed that the ATP contained 94.64% Fe, 0.32% C, 1.20% Mn, 1.00% Cr, 0.30% Ni, 0.00%V,1.80% Si, 0.015% P, 0.016% S, 0.70% Mo and 0.005B. NST 65 Mn steel was found to contain 97.78% Fe, 0.30%C, 1.04% Mn, 0.01% Cr, 0.01% Ni, 0.10%V 0.02% Si, 0.005% P, 0.015% S, 0.02% Cu, 0.70% Mo, and 0.00% B., and SS steel was found to have 97.49% Fe, 0.30% C, 0.53% Mn, 0.12% Cr, 0.12% Ni, 0.00% V, 0.21% Si, 0.01% P, 0.30% S, 0.22% Cu, 0.70% Mo and 0.00% B.

The armoured tank panel investigated was found to be Ni-Cr-Mn-Mo-B steel. NST 65 Mn Steel and SS Steel are among the most widely used steel products in the Nigerian construction industry. The characterization of these steels revealed that NST 65 Mn Steel is a manganese steel containing mainly Mn, V, Mo, Cr, Ni, Cu, and Si. SS Steel was characterized as containing mainly Mo, Mn, Cu, Cr and Ni. The two steels were found to have the same carbon content. Alloying has been identified as one of the most important ways of improving the mechanical properties of steel, Bain and Harold (1966); Pickering (1977); Davies (2005); and Campbell (2011). Basic principles in the design of alloy steels for high strength applications was said to depend on the amount of carbon and that of the different strengthening mechanisms that are used for low, medium and high carbon steels, Bain, (1977); Campbell, (2011). Campbell (2011) also showed that the combination of Ni-Cr-Mo in steel provides it high strength, high hardness and soft ductile core. This combination is found in varying amounts in all the three materials studied above.

The manganese content in the ATP was found to be 1.20%. That of NST 65Mn determined as 1.04% and SS steel was found to contain 0.53%. Davies (2005); Jain (2010) and Campbell (2011) stated that manganese contributes to strength and combines with sulfur to improve machinability; also Davies (2005) showed that it adds to tensile strength makes austenite more chemically stable. This was also stated in Metallurgical Consultants (2006). Manganese also increase hardness penetration Edward and Mathewson (1997); McGraw Hill (2003).

Chromium causes significant increase in strength and provides pearlitic matrix and an associated increase in hardness Hermann and Leroy (1996). Davies (2005) stated that chromium is added to steel principally to increase resistance to corrosion and oxidation. It was also said to increase resistance to abrasion in high carbon compositions. The chromium content in the materials was analyzed to be 1.00%, 0.01% and 0.12% for the ATP, NST 65 Mn steel and SS steel respectively.

The chemical analysis showed that the ATP contained 0.30% Ni, NST 65 Mn steel contains 0.01% and SS steel contains 0.12% Ni. Nickel used as an alloying element strengthens ferrite and remains in solid solution. It was also said to combine with Chromium to provide alloy steels with greater hardinability, higher impact strength and fatigue resistance than can be achieved in carbon steels Heutrich et al (1971) and Davies (2005). Bolton (1989) and Smith (1993) also stated that Nickel increase toughness and hardness.

Deelay et al, (1981); Taylor, (1995); Bain and Harold, (1966) and Campbell, (2011) stated that Silicon when used as a deoxidizer in the manufacture of steel increases tensile strength of steel, increase toughness and penetration hardness. Vanadium was said to help control grain growth, by inhibiting austenitic grain growth and also improves yield strength in steel; Deelay, (1981); Mac Gammon, (1985); Parr, (1986) and Davies, (2005). United Steels Company, (1999) reports that vanadium is strong carbide and nitride former, strongly increases resistance to softening during tempering and also an effective grain refiner and ties up with nitrogen to inhibit strain ageing. Parr, (1986) also stated that vanadium in low carbon steel provides high strength and good impact resistance. Davies, (2005) also reported that vanadium in amounts up to about 0.05% increases hardenability in steels.

Copper addition in amounts of 0.2 to 0.5 percent was found to primarily improve steel resistance to atmospheric corrosion, but has detrimental effect to surface quality, the risk of hot shortness (tearing during hot working, including forging), stiffening of ferrite and decrease in ductility; Deelay, (1981), Primos, (2007). Molybdenum increases hardenability of steel and is particularly useful in maintaining the hardenability between specified limits. It was also said to minimize the susceptibility of steel to temper embrittlement especially in amounts between 0.15 to 0.30%; Davies, (2005). Davies, (2005) stated that Boron is added to fully killed steel to improve hardenability, but that when used to substitute other alloying elements, it must be done only with hardenability in mind because lowering alloy content may be harmful to other applications. Sulfur improves machinability but is detrimental to surface quality and decreases impact strength, ductility, and weldability; Taylor, (1995); Key-to-Steel, (2007). It's most important role of improved machinability is over looked where tensile strength, impact strength and other properties are critical. In Davies, (2005) increased sulfur content was said to lower transverse ductility and notch impact toughness with only light effect on mechanical properties.

Mac Gammon, (1985); Parr, (1986); and United Steel Company, (1999) stated that Phosphorous has been observed as an impurity in steel, that has to be refined out, and that it's excess adds to energy consumption. However, despite its detrimental effect, steel makers observe that phosphorous improves hardinability and corrosion resistance and therefore a maximum limit specified.

The chemical compositions of the materials are very important to their suitability in the production of armoured tank panel which requires that the material most posses desired impact strength and hardenability. It was concluded by the Naval Research Laboratory, USA at the investigation on the failure of the liberty ship that steel for high impact application must absorb not less than 20 joules of impact energy. The chemical compositions, hardness and impact strength of NST 65 Mn steel and SS steel were determined. NST 65 Mn steel was found to be superior to SS steel in hardness and impact strength and therefore selected as the base material.

Table 4.2 shows the results of the Rockwell hardness tests conducted on the materials. For each material, three readings were taken and the results averaged. The Rockwell hardness number of the ATP was averaged at 117 HRB, NST 65 Mn steel averaged 84.8 HRB and SS steel was averaged at 83.5 HRB. Table 4.3 shows the results of the V – Notch Charpy impact test carried out on the materials. Three impact test samples were prepared for each material and the tests conducted under the same conditions using the same equipment and standards. The results of the tests were also averaged and the impact strength of the ATP was averaged at 109 Joules, NST 65 Mn steel averaged at 70 Joules and SS steel was averaged at 67 Joules.

The total content of the alloying elements for ATP was 5.356% with carbon, manganese, chromium, nickel, Silicon and molybdenum as the major alloying elements. NST 65 Mn Steel has total alloy content of 2.22% with carbon, manganese and molybdenum as major alloying elements, and SS steel has a total of 2.51%, with molybdenum, manganese, nickel, silicon and copper as the major elements. The sulfur and phosphorus content of SS steel found to be higher than that of ATP and NST 65 Mn steel. Table 4.1 also showed that the carbon content of the ATP was higher than that of NST 65 Mn steel and SS steel that was found to be the same.

The results of mechanical tests revealed that the ATP has superior hardness and impact strength compared to that of NST 65 Mn steel and SS steel tables 4.2 and 4.3. This can be attributed to higher percentages of carbon, manganese; chromium, nickel, silicon and the presence of boron with lower sulfur and phosphorus content also zero percent copper. Rajan et al, (1973); Leslie, (1981); and Testing- Terms, (2007-8) stated that strength is primarily related to both carbon and alloy content and to the type of heat treatment. Ashby and Jones, (1996) stated that carbon is the most cost effective alloying material for iron but that various other alloying elements such as manganese, chromium, vanadium, nickel, and tungsten are used. Davies, (2005) described carbon as one of the most potent alloying elements in its effect on notch toughness and strength, but that for maximum toughness its content should be kept as low as possible consistent with strength requirements.

Carbon was reported to have dual effect in hardenable alloy steels and that it controls the maximum attainable hardness and contributes substantially to hardenability, with the latter being enhanced by the quantity and type of alloying elements present, Davies, (2005) and Campbell, (2011).

In comparison, the higher hardness and impact strength of the NST 65 Mn to that of SS Steel was attributed higher content of manganese, the presence of vanadium and lower content of phosphorous, sulfur and copper. Although the chromium, nickel and silicon content of SS Steel are higher than those found in NST 65 Mn Steel, the much higher percentages sulfur, phosphorus, copper, zero vanadium in SS Steel, quality and source of raw materials was responsible for its lower hardness and impact strength.

## 6.0 Conclusions

1. Hardness of NST 65 Mn Steel averaged at 70 HRB was higher than that of SS Steel averaged at 67 HRB.
2. Impact Strength of NST 65 Mn was averaged 84.8 Joules which is higher than that of SS Steel averaged at 83.5 Joules.
3. With the higher potential of enhanced mechanical properties, reduced machining requirement, better raw material quality, energy saving and cost savings, the NST 65 Mn Steel is a better choice as a base material for the production of High Impact Resisting Panel Material.

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