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DEVELOPMENT OF HIGH IMPACT RESISTING MATERIAL USING NIGERIAN STEEL 65 Mn STEEL AS A BASE MATERIAL

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Abstract

Nigerian Steel 65 Mn (NST 65 Mn) was used as a base material for the development of High Impact Resisting Material. Two new materials, New Material 1 (NM 1) and New Material 2 (NM 2) were developed by increasing the alloy content of manganese, chromium and Nickel in the base material using master alloys. Chemical analysis was carried out according to ASTM E 572-02a (2006) e2. Mechanical Tests were also conducted as specified by ASTM A 370, E 8, E 10, E 18 and E 23using standard samples and equipment. The tests were conducted per sample and results averaged. NST 65 Mn Steel was found to have Rockwell Hardness Value of 84.8 HRB, Impact Strength of 70 Joules, and Tensile Strength of 551.6 N/mm^2. NM 1 was found to have Rockwell Hardness Value of 125 HRB, Impact Strength of 111 Joules, and Tensile Strength of 1,744 N/mm^2. NM 2was found to have Rockwell Hardness Value of 114 HRB, Impact Strength of 73 Joules, and Tensile Strength of 1,317 N/mm^2. The mechanical tests conducted on Armoured Tank Panel (ATP) in previous research sited revealed that it has Rockwell Hardness Value of 117 HRB, Impact Strength of 109 Joules, and Tensile Strength of 1,420 N/mm^2. The results showed that the NM 1is better in mechanical properties than NST 65 Mn Steel, NM 2 and ATP. The New Material 2 is better than NST 65 Mn steel in but less than the ATP. The results established that New Material 1 can be used as a material for High Impact Resistance and therefore the potentials of NST 65 Mn Steel as base material is high.

Key Words: *High Impact Resisting Material, NST 65 Mn Steel, Hardness Test, Impact Test, Tensile Test, New Material 1, New Material 2.*

1. Introduction

Most material selection for the manufacture of Engineering components require some form of compromise, as each material offers different blend of hardness, yield strength, thermal conductivity, workability, rust corrosion resistance, cost, and method of manufacture etc. In this paper the Nigerian Steel 65 Mn (NST 65 Mn Steel) which was found to be the better than the Nigeria Spanish Steel (SS Steel) in terms of Chemical composition and Mechanical properties for the production of high impact resisting material when studied along with Armoured Tank Panel (ATP) Material as shown in previous work (Determination of Suitable Locally Produced Steel in Nigeria as a Material for the Production of High Impact Resisting Material) published in G.J.E.D.T., Volume 2(4) : 67-71 July-August 2013 was used as a base material for the production of high impact resisting material.

In the work mentioned above, the Amoured Tank Panel investigated was found to be Ni-Cr-Mn-Mo-B steel. Also the characterization of the two most widely used steel products in the Nigerian construction industry the NST 65 Mn and Nigerian Spanish Steel (SS Steel) revealed that NST 65 Mn Steel is a manganese steel containing mainly Mn, V, Mo, Cr, Ni, Cu, and Si. The SS Steel was characterized to contain Mo, Mn, Cu, Cr and Ni. The two steels were found to have the same carbon content.

Alloying was used to improve the NST 65 Mn Steel to meet the requirement for high impact resisting material. 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, Campbell (2011).

Manganese, Chromium and Nickel were selected as the alloying elements to be used in improving the selected base material to be developed. Campbell (2011) showed that the combination of Ni-Cr-Mo in steel provides it high strength, high hardness and soft ductile core. Davies (2005); Jain (2010) and Campbell (2011) stated that Mn 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 provide pearlitic matrix and an associated increase in hardness, Hermann and Leroy (1996); Davies (2005).

Nickel used as an alloying element strengthens ferrite and remains in solid solution. It was 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. The chemical composition of the materials is therefore very important to their suitability in the production of high impact resisting material 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 determined in previous study was found to be adequate and the material most suitable among the others for use as a base material for the production of high impact resisting material.

2. Development of New Material

The development of the high impact resisting material from the selected Nigerian steel used as base material was done through the process of Electric arc furnace (EAF) – Ladle furnace (LF) – Vacuum degassing (VD) Continuous casting process (CCP). EAF with electronic tilting facility was used to melt the steel and the molten steel was adequately deoxidized using Al and other deoxidizers in a preheated ladle, where the slag was also tapped. The addition of ferroalloys (Ferro-Manganese, Ferro- Chrome and Nickel) to achieve the desired chemistry was done in the ladle furnace station after which the ladle was transferred to VD station for vacuum degassing. Two new materials, New Material 1 and New Material 2 were developed with different chemistry using the same process. The molten steel was cast in a rectangular iron mould through continuous cast process to produce billets measuring 300 x 120 x 30mm and the billet rolled to a reduction ratio of 1:6 after which the mechanical test specimen were produced from the rectangular billets. Confirmatory chemical analyses were carried out using Minipal 4 EDXRF.

3. Determination of Chemical Composition

The chemical analysis of the NST 65 Mn Steel, New Material 1 and New Material 2 were 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 by X-ray fluorescence spectrometry.

4. Determination of Mechanical Properties

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 with ASTM standardizing the tests, Kalpakjan, (1991); American Society of Metals, (1988). Tensile test was also carried out on the materials as the test provides useful information for alloy development, comparison of materials and design under certain circumstances, Lord and Dermorest (1982), Taylor (1995).

5.0 Results

Table 5.1 shows the results of Chemical analyses of NST 65 Mn Steel, NM 1 and NM 2 carried out using Minipal 4 EDXRF spectrometer according to ASTM E572-02a (2006) e2- standard test methods for analysis of stainless and alloy steels by X-ray fluorescence spectrometry. Table 5.2 shows the results of Rockwell hardness tests on the materials according to ASTM A 370, ASTM E 10 and ASTM E 18 using standard equipment. Table 5.3 shows the results of impact tests carried out according to ASTM E 23 standard test method for Charpy 45^{o} V- Notch for rectangular bars. Table 5.5 shows results of tensile test carried out according to ASTM E 8 standard test for circular sections.

Table 5.1: Chemical composition of NST 65Mn steel, New Material 1 and New Material 2

Materials	Chemical composition %									
	Fe	C	Mn	Cr	Ni	V	Si	P	S	Cu	Mo
NST 65 Mn Steel	97.78	0.30	1.20	0.01	0.01	0.10	0.02	0.005	0.015	0.02	0.70
New Material 1	92.28	0.32	1.24	1.80	3.50	0.10	0.02	0.005	0.0145	0.02	0.70
New Material 2	93.09	0.31	1.14	1.30	3.30	0.10	0.02	0.005	0.0146	0.22	0.70

Table 5.2: Results of Rockwell Hardness Test on B-Scale on NST 65 Mn Steel, New Material 1 and New Material 2

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	
NST 65 Mn Steel	98	980	B-Scale	101.2 HRB Plate	1.6mm Steel Ball	85	84.8	85	84.8
New Material 1	98	980	B-Scale	101.2 HRB Plate	1.6mm Steel Ball	121	124	130	125
New Material 2	98	980	B-Scale	101.2 HRB Plate	1.6mm Steel Ball	104	114	124	114

Table 5.3 Results of Charpy V-Notch Impact Test

Material	Impact Velocity m/s	Energy Absorbed (J) Test 1	Energy Absorbed (J) Test 2	Energy Absorbed (J) Test 3	Average Energy Absorbed (J)	Type of Specimen
NST 65 Mn Steel	5.24	72	71	68	70	Standard Rectangular
New Material 1	5.24	112	109.5	110	111	Standard Rectangular
New Material 2	5.24	73	71	75	73	Standard Rectangular

Table 5.4: Results of Tensile Test on Materials

MATERIAL	TENSILE STRENGTH N/mm^2 TEST 1	TENSILE STRENGT N/mm^2 TEST 2	TENSILE STRENGTH N/mm^2 TST 3	AVERAGE TENSILE STRENGTH N/mm^2
NST 65 Mn Steel	552.6	549.7	552.6	551.6
New Material 1	1599.2	1745.3	1887.5	1744
New Material 2	915.5	1311.1	1724.5	1317

6.0 Discussion of Results

Table 5.1 shows the results of the chemical analysis carried out to characterize the NST 65 Mn steel, New Material 1 and New Material 2. The choice of NST 65 Mn Steel as base material was due to its availability, material processing, and adherence to standards, quality control, mechanical properties and chemistry as determined in previous work. Table 5.1 showed that NST 65Mn 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 and 0.70% Mo. NST 65 Mn Steel was found to have total alloy content of 2.22% with carbon, manganese and molybdenum as major alloying elements

Previous research effort showed that strength is primarily related to both carbon and alloy content and to the type of heat treatment, Testing Terms (2007), Rajan et al (1973), Leslie (1981). Also 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, Ashby and David (1992).

Manganese contributes to strength and hardness. It was also said to combine with sulfur to form manganese sulfide stringers which improve machinability of steel, Davies (2005), Campbell (2011), Jain (2010). It also has strong effect on increasing hardinability, by shifting the nose of the TTT diagram slightly to the right and refines and strengthens pearlite Campbell (2011), Jain (2010). Manganese in steel adds to tensile strength and make austenite more chemically stable, Metallurgical Consultants (2006), Timings and May (1990). It also increases hardness penetration, McGrraw Hill (20003), Edward and Mathewson (1997) , Huetrich et al (1971).

Chromium causes significant increase in strength, promotes a pearlitic matrix and an associated increase in hardness, Davies (2005), Parr (1986), Herman and Leroy (1996). It also improves hardinability, wear resistance and strength, also as a strong ferrite stabilizer combines with carbon to form carbides, Campbell (2011), Jain (2010).

Nickel used as an alloying element strengthens ferrite and remains in solution in the ferrite, thus strengthening and toughening the ferrite phase. In combination with chromium, nickel produces alloy steels with greater hardinability, higher impact strength and greater fatigue resistance than can be achieved in carbon steels Davies (2005). Nickel and manganese in steel add to tensile strength and make austenite more chemically stable, Metallurgical Consultants (2006), Timings and May (1990). The strength of ferrite was reported to have increased with the presence of nickel and when the element is used in low alloy steel it increases toughness, hardness and tends to reduce distortion and cracking during quenching, Bolton (1989), Smith (1993), United Steels Company (1999).

New Material 1 and New Material 2 were then designed and produced using NST 65 Mn steel as the base material with increased content of manganese, chromium and nickel with a view to improving mechanical properties and producing a high impact resisting material.

Table 5.1 presents the results of the chemical analysis of the NST 65 Mn Steel and the two newly designed and produced materials; New Material1 and New Material 2. The main difference between the two new materials is in the percentages of the major alloying elements.

The manganese content in the base material was increased using ferro-manganese additive (49% Mn and 51% Fe) from 1.04% to 1.24% and 1.14%; chromium content was increased using ferro-chrome additive (66.5%Cr, 6.4%C and 27.1%Fe) from 0.01% to 1.80% and 1.30; Also nickel content was increased using nickel additive (99% Ni and 1% Fe) from 0.01% to 3.50% and 3.30% in New Material 1 and New Material 2 respectively. The use of ferro- chrome additive increased the carbon content from 0.30%C in the base material to 0.32%C and 0.31%C in the New Material 1 and the New Material 2 respectively.

Rockwell hardness test on 'B'scale carried out on the materials gave the results on table 5.2 and The results showed that the NST 65Mn Steel was found to be 84.8 HRB. The hardness of the new materials, the New Material 1 and the New Material 2 were determined to be 125 HRB and 114 HRB respectively. The effect of the alloying elements caused the increase in hardness of NST 65 Mn from 84.5 HRB to 125 HRB in New Material 1 and 114 HRB for New Material 2 which are both higher than that of NST 65 Mn Steel.

The increase in the alloying elements, particularly chromium resulted in carbon pick up that increased the carbon content to 0.32% and 0.31% for New Material 1 and New Material 2 respectively from 0.30% of NST 65 Mn steel. This increase in carbon content together with that of other elements is also a factor responsible for the increase in the hardness value, as alloying elements and the form of their presence controls qualities such as hardness, ductility and tensile strength, Edward and Mathewson (1997), Ashby and David (1992).

The ductility of NST 65Mn steel was also found to increase from 70 joules to 111 joules and 73 joules at impact velocity of 5.42 m/s for New Material 1 and New Material 2 respectively, table 5.3. The higher content of Nickel in New Material 1 can be attributed to the increase in ductility. This is in line with previous research which showed that tensile strength and ductility of commercial 3.5% Ni steel surpasses that of 2.25% Ni steel and that of the strength of 5% Ni steel surpasses that of the 3.5% Ni steel, Huetrich et al (1971). Also in line with literature which states that nickel and chromium in amounts up to 10% by weight are allowed to improve hardinability of steel, Davies (2005), Parr (1986). Ductility is an important property of the high impact resisting material. It enables it to absorb more impact loading.

Impact tests were used by the Naval Research Laboratory, USA to investigate the failure of the Liberty Ship and came up with the conclusion that steel for high impact resistance application must absorb not have less than 20 joules impact energy for a given size of specimen.

The decrease in sulfur content may have contributed to increase in ductility and notch impact toughness. This is supported by literature that states that increase in sulfur content lowers traverse ductility and notch impact toughness, but with only slight effect on longitudinal mechanical properties. It also showed that when high sulfur is accompanied with an increase in manganese content a better surface finish is obtained which usually results in improved dimensional accuracy, Davies (2005). This is in line with literature that states that up to 1.5% Mn is allowed to increase impact strength for a modest price, School Science (2007), American Institute of Iron and Steel (2006).

Tensile tests results in table 5.4 showed that the tensile strength of NST 65 Mn improved from 55.6 N/mm^2 to 1744N/mm^2 and 1317N/mm^2 for New Material 1 and New Material 2 respectively. The increase in the alloying elements in NST 65Mn steel caused the increase in the tensile strength of New Material 1 to 1744N/mm^2 which surpasses that of NST 65Mn steel. It also increased the tensile strength in New Material 2 to 1317N/mm^2 which also surpasses that of the base material NST 65Mn. These results agree with findings of other works that stated that nickel and manganese in steel add to the tensile strength and make austenite more chemically stable, Metallurgical Consultants (2006).

The results showed that the increase in Manganese, Chromium and Nickel content of NST 65 Mn Steel significantly improves its mechanical properties as shown in the new materials produced.

7.0 Conclusion

In conclusion,

1. The composition and mechanical properties of the NST 65 Mn steel was determined and based on which it was selected as the base material for the production of high impact resisting material.
2. Two new materials, New Material 1 and New Material 2 were developed using NST 65 Mn Steel.
3. The two new materials were analyzed to confirm their composition and mechanical properties.
4. Mechanical properties tests showed that the New Material 1 is superior to New Material 2 and NST 65 Mn Steel and is also comparable to but superior to the Armoured Tank Panel (ATP) material earlier studied.
5. The tests also showed that the New Material 2 is better than NST 65 Mn Steel, comparable to but inferior to the ATP material.
6. Tensile strength of New Material 1 was highest and averaged 1744 N/mm^2 followed by the ATP material averaged at 1420 N/mm^2, New Material 2 with1,317 N/mm^2 and NST 65 Mn Steel averaged at 551.6 N/mm^2
8. The hardness of New Material 1 was highest, averaged at 125 HRB, followed New Material 2 with 114 HRB and NST 65 Mn steel with 84.8 HRB. The ATP material earlier studied was averaged at 117 HRB.
9. New Material 1 failed at an average impact load of 111 Joules, New Material 2 at 73 Joules, NST 65 Mn Steel failed at 70 Joules and the ATP failed107 Joules. New material 1 was found to posses' higher toughness value.
10. The potential of NST Mn Steel as a base material for the production of high impact resisting material is therefore very high.
11. The work showed high potential of enhanced mechanical properties and chemical properties by the two new materials developed. New Material 1 and New Material 2 can be used as high impact resisting materials.

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References

American Society of Metals (1988) "*Standard Test for Bar Impact test of Metallic Materials*" ASM, Philadelphia, Unitd States of America.

American Society of Testing and Materials (1988) "*Methods for Chemical Analysis of Metals*" ASTM, Philadelphia,

United States of America.

American Institute of Iron and Steel AISI (2006) "*Steel Glossary*" Retrieved 2006.

Amptiac Quarterly (2004) "*Adapting to Challenges of Battle Field*" Department of Defence Technical Information Centre, United States of America.

Ashby, M.F. and David, R.H.J. (1992) "*Engineering Materials 2*" (with correction edition) Oxford, Paragon press. ISBN 0 – 08 – 032532 -7. Darayaganji, New Delhi – 110002 ISBN 81-7409-099-1

ASTM A370 "*Standard Test Method and Definition of Mechanical Testing of Steel Products – Standard for Charpy V Notch Bar Impact Test for Metallic Materials*" ASTM, Philadelphia, USA.

ASTM E8 "*Standard Test for Tension Test for Metallic Materials*" American Society of testing of Materials, ASTM, Philadelphia, USA.

ASTM E10 "*Standard Test Method for Brinell Hardness Test for Metallic Materials*" ASTM, Philadelphia, USA.

ASTM E18 "*Standard Test Method for Rockwell Hardness Test for Metallic Materials*" ASTM, Philadelphia, USA.

ASTM E23 "*Standard Test Method for Bar Impact Test for Metallic Materials*" ASTM, Philadelphia, USA.

ASTM E572-02a (2006) e2 - Standard Test Method for Analysis of Stainless and Alloy Steels by X- Ray Fluorescence Spectrometry.

Bain, E.C. and Harold, W.P. (1966) "*Alloying Elements in Steel*" Fifth Edition ASTM Publishers, Metals Park Ohio. p 88-150

Bolton W. (1989) "*Production Technology*" Butterworth – Heinemann. ISBN 0-7506-1594-4.

Campbell, F.C. (2011) "*Elements of Metallurgy and Engineering Alloys*" American Society of Metals (ASM) International, Metals Park, Ohio 44073-0002 USA. pp 371-393

Davies, J.R. (2005) "*Alloying – Understanding the Basics*" American Society of Metals, Metals Park, Ohio 44073-0002 ISBN 0-8717-744-6. pp137-150

Edward, M.R. and Mathewson, A. (1997) "*The Ballistic Properties of Tool Steels*" Internal Journal of Impact Engineering 19/5.

Global Journal of Engineering, Design and Technology (2013) volume 2(4) pp 67-71 July-August 2013.

Heutrich, N.J. Pence, A.W. and Stout P.D. (1971) "*The Toughness of 2.5% and 3.5% Nickel Steel at Cryogenic Temperature*" Welding Research Bulletin 165 Sept. 1971.

Hermann, J.C. and Leroy, V. (1996) "*Influence of Residual Element on Steel Processing and Mechanical Properties*" Rue Ernest, Solvey, Liegh, Belgium.

Jain, R.K. (2010) "*Production Technology*" Khanna Publishers, 4575/15 Onkar House, India.

Kalpakjan, S. (1991) "*Manufacturing Process for Engineering Materials*" Addison, Wesley, ISBN 0-201-11690-1

Leslie, W.C. (1981) "*The Physical Metallurgical of Steels*" Mc Graw Hill Company, Incorporated. UK.

Lord, N.W. and Dermorest D.J. (1982) "*Metallurgical Analysis*" Mc Graw Hill, New York, 6th Edition.

Mc Graw Hill, (2003) "*Hard Field Manganese Steels*" Mc Graw Hill Dictionary of Science and Technology. Mc Graw Hill Company, Incorporated. UK. Answers.Com (Retrieved 2007).

Metallurgical Consultants (2006) "*Alloying of Steels*" Retrieved April, 2007.

Naval Research Laboratory Report on Liberty Ship Failure.

Parr, J.G. (1986) "*Modern Steels and their Properties*" Bethlehem Steel Company Publishers, Bethlehem Pa.

Pickering, F.B., (1977) "*Micro Alloying, High Strength, Low Alloy Steels*" 75 Process International Conference, Union Carbide Corporation. England.

Rajan, V.J, Sharma, C.P. and Sharma A. (1973) "*Heat Treatment principles and Techniques*" Prentice Hall of India private Ltd. New Delhi.

School Science.co.uk (2007) "*High Strength Low Alloy Steel*" Retrieved 2007.

Smith, W.F. (1993) "Fundamentals of Material Science and Engineering" Mc Graw Hill ISBN 0-07-059292-0.

Taylor C.R. (1995) "*Electric Furnace Steel making*" Iron and Steel Society of AIME, 410 Common Wealth Street, Warren.

Testing Terms (2007-8) www.tpub.com Sited March, 2009.

Timings, R. and May, T. (1990) "*Mechanical Engineering Pocket Hand Book*" Newness-Butterworth- Heinmann ISBN 0-1806-0919-2.

United Steel Company (1999) "*Standard Steel and Ferro-Alloying*" USC, Sheffield, UK.