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The Effect of Various Heat Treatments on the Hardness of Some Nigerian Steels

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Abstract: Two indigenous steel, NST 37-2 and NST 60Mn were studied to determine the effect of various heat treatments on their hardness. Results indicate that water seems to be most efficient quenching medium where maximum hardness is required. However, where hardness can be sacrificed, mineral oil can be used for quenching. NST 60Mn steel, with higher manganese and carbon contents showed greater hardness at fast cooling rate. This greater hardness was due to the greater amount of martensitic transformation and precipitation hardening of carbides (Fe_3C). The air-cooled samples did not show much increase in hardness because, the steels transform more into ferrite and very little of pearlite. The technological importance of the results obtained in relation to Nigerian Structural Adjustment Programme (SAP) are discussed.

Introduction

Heat treatment represents a major part of the thermomechanical processing of most engineering materials which is one of the features that control the microstructure of steels. It also affects the proportion, size and distribution of the phases by an equilibrium or non-equilibrium partitioning, dislocation and defeat structures (1). Heat treatment also affects the grain size. The grain growth under the influence of annealing treatments have been extensively studied (2-4) and the associated benefits have been stressed. There is a technological interest in using grain growth to achieve large grained as well as fine grained products. An example is the established technique for the manufacture of iron-silicon transformer sheet, which relies on secondary recrystallisation induced by a strong texture (5), to achieve a large grain sized product with the correct, low loss texture. The importance of this as a technique has led to many fundamental studies of grain boundary migration in this material (1).

The fundamental studies have helped to understand better about the technology of heat treatment. The change in the mechanical properties have been ascribed to the change in the structures of the materials as a result of heat treatment. As steels are heated to upper critical temperature range, the phase diagram shows that the stable structures will be austenite, also known as the γ phase, which has an FCC structure (6). Depending on how rapidly this phase is cooled to room temperature, a variety of distribution of phases can be produced.

Very slow cooling (in this context termed "Full Annealing: produced a phase mixture of ferrite (α Phase which has a BCC structure) and pearlite (which itself is a phase mixture of ferrite and cementite (Fe_3C).

Faster cooling to room temperature e.g. air cooling or normalising and gives ferrite and pearlite but the scale of the structure will be somewhat finer than for full annealing. This is also applied to oil cooling [7].

Rapid cooling, e.g. water quenching, produces a structure not predicted by the phase diagram. this is Martensite which is a supersaturated solution of carbon in BCC iron. The effect of the supersaturation is to distort the structure to a body centred tetragonal structure [6]. Heat treatment therefore is very important in producing hard steels that are used for major constructions. The production had steel is very important especially in regions where effoits is placed towards development of carbon steels to be used in construction industries. this led to the establishment of three inland rolling mills by the Federal Government of Nigeria at Osogbo, Jos and Katsina. The main input material for the rolling mills would be carbon steels billets from Aladja Steel Plant.

Aladja Steel Plant employs the midrex direct-reduction process that reduces hematite Fe_2O3 iron ore which contains about 70% iron to 92.25% of iron pellets. this could be possible by using natural gas, which is abundant in Nigeria as the reductant. The pellets would then be fed into electric arc furnace with scraps and other additives like lime stone to produce liquid steel. the liquid steel would then be processed further into billet by using continuous casting methods.

These billets from aladja Steel Plant, to the inland Rolling mills would produce merchant bars from 12mm to 40mm (round 12-40mm or reinforcement bar 12.25mm) and wire coil from 6mm - 12mm. This can be plain 6mm - 12mm or reinforcement wire 8mm - 12mm. They can be strengthened by cold work. these products of low-alloy steels are used mostly for constructional purpose. they could also be used for making nails, bolts, nuts, rivets, wire mesh, machine parts, shafts, connecting rods, automobile components, binding wire, telegraphic wire barbed wire chain link and for other purpose [8].

The billets produced and sent to the rolling mills from aladja are in the different qualities: RST-37-2, ST-44-2, ST-60Mn, ST-50-2, ST-60-2, ST-70-2. They are all constructional steels based on German Standard, of DIN 17100.

The Nigerian Standards Steel produced at Aladja are Nst-60Mn, NST-37-2 and NST-37-LC which are equivalent to DIN 488 and DIN 17100. Steel is steel any where in the world and the chemical composition must conform with he international standard. The nomenclature can only change; Nigeria has her own steel nomenclature which is known as "Nigerian Standard". These steels were used in this work.

The aim of this work is to examine the effect of various heat treatments on the hardness of some Nigerian Steels. The result would provide awareness of the strength of these steels that can be derived from heat treatment. Results could also be beneficial to small scale industries which may use heat treatment as a secondary process to fabricate these steels into various components.

Experimental procedure

The Nigerian Steels NST 37-2 and NST 60Mn (was supplied by Osogbo Steel Rolling company). The composition of the steels (was kindly analysed by the British Steel Corporation, Newport, U.K.) used in the study is given in Table 1. The hardness specimens were heat treated at the furnace between 750°C and 900°C for 30 minutes for the heat treatment experiments. Some of the specimens, were non-heat treated to ascertain their hardness in as-rolled condition.

Table 1: Chemical Analysis

Sample	C	S	Mn	P	S	N	Cu	S	N	Al	Cr
NST37-2	0.238	0.323	0.008	0.015	0.057	0.057	0.038	0.021	0.086	0.00	0.048
NST60Mn	0.386	0.161	0.92	0.038	0.006	0.18	0.012	0.004	0.0061	0.003	0.039

Three media of quenching employed were air, mineral oil, and water. Prior to hardness measurement the specimens were given a standard surface finish by grinding on silicon carbide papers from 220 to 600 mesh grades after quenching. All hardness measurements were carried out on a Vickers hardness testing machine using a diamond pyramidal indentor and a 30kg load.

The hardness number quoted in the results is the mean of at least twenty separate indentations.

Results and discussion

Table 2, shows the hardness of both steel as-rolled condition. Tables 3-5, show the various hardness readings at the different cooling media.

Table 2: As-Rolled Condition

Sample	Hardness Value (Hv30)
NST37-2	143
NST60Mn	192

Table 3: Air-Cooling

Temperature (°C)	Hardness value	
	Sample NST 37-2	Sample NST60Mn
750	147	169
800	10	199
850	154	213
900	153	206

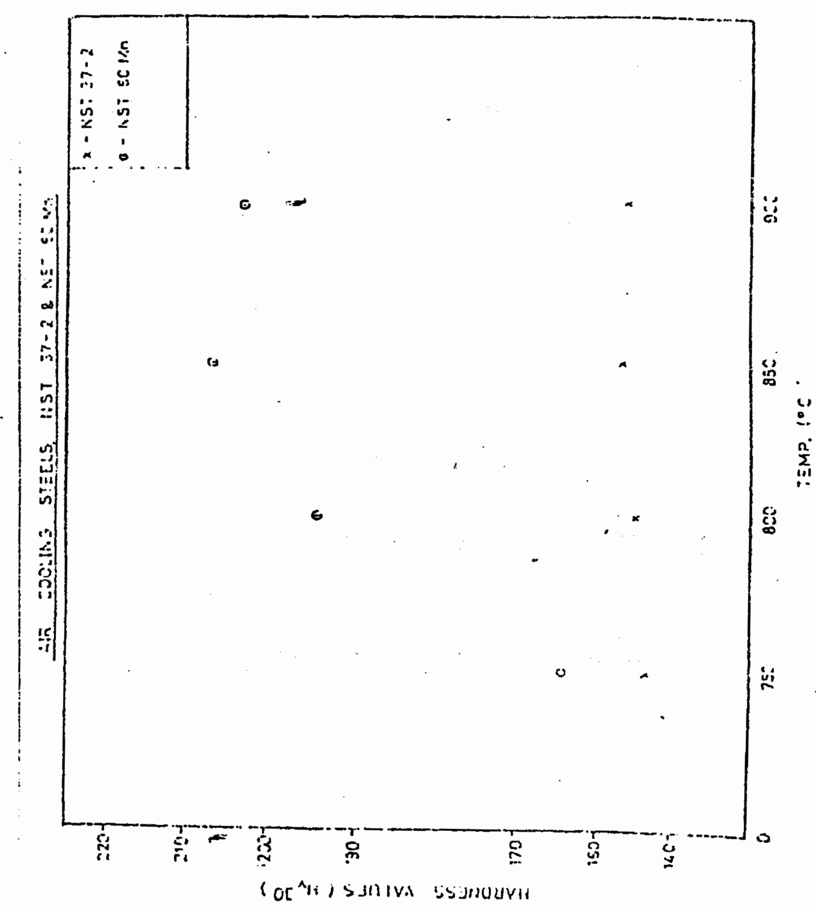
Table 4: Oil-Cooling

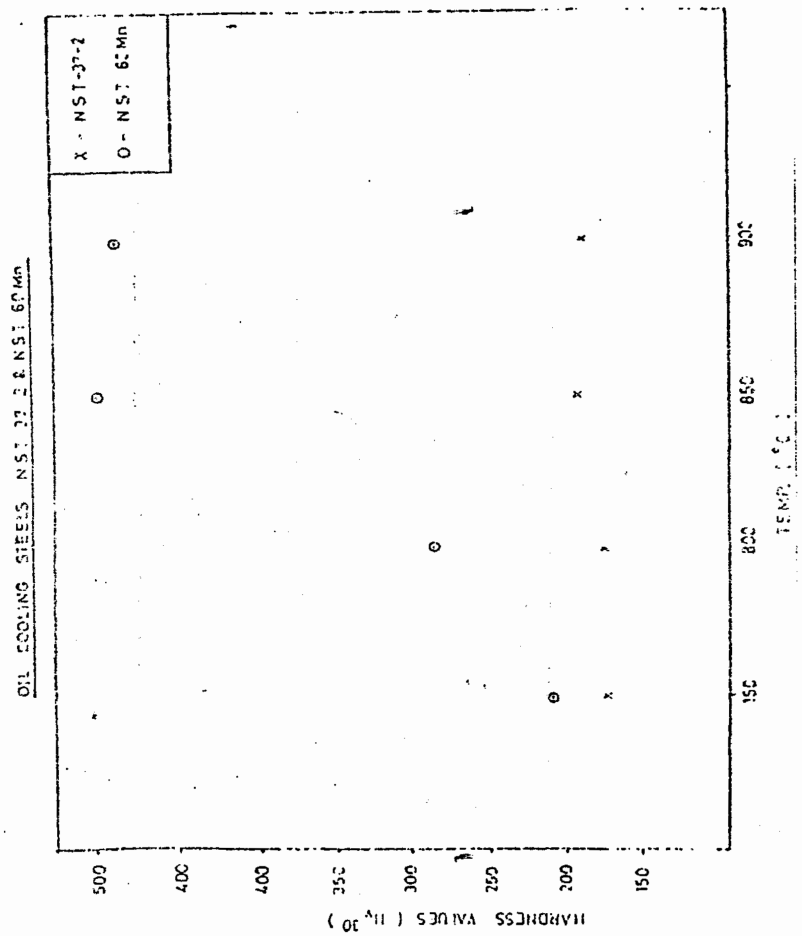
Temperature (°C)	Hardness value	
	Sample NST 37-2	Sample NST60Mn
750	175	213
800	178	287
850	192	495
900	191	

Table 5: Water-Cooling

Temperature (°C)	Hardness value	
	Sample NST 37-2	Sample NST60Mn
750	210	277
800	255	561
850	467	578
900	447	630

Figures 1-3 indicate the curves of hardness against the austenitizing temperatures while Figures 4-9 show the micro structures at various cooling media. The air-cooling media results seem to have a little increase in the




OIL COOLING STEELS NST 37-2 & NST 60 Mn
X - NST 37-2
O - NST 60 Mn
TEMP. (°C)
HARDNESS VALUES (Hv 30)

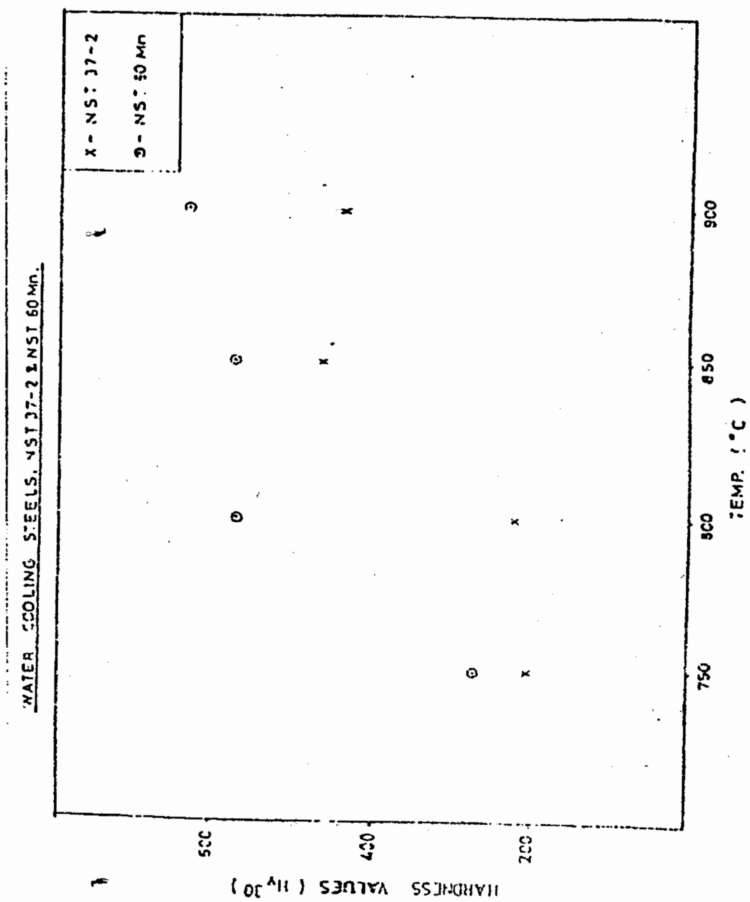

WATER COOLING STEELS, NST 37-2 & NST 60 Mn.
X - NST 37-2
O - NST 60 Mn
TEMP. (°C)
HARDNESS VALUES (Hv 30)

Figure 3

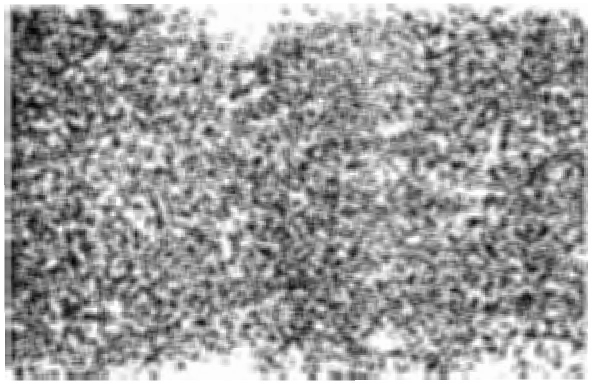


Fig. 4: NST37-2 ~ Heat Treatment at 900°C and Water-Cooled

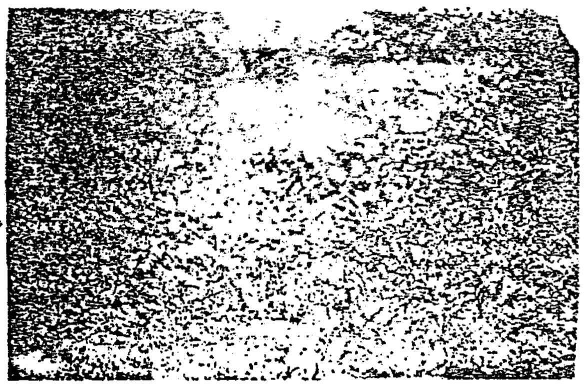


Fig. 5: NST60Mn ~ Heat Treatment at 900°C and Water-Cooled

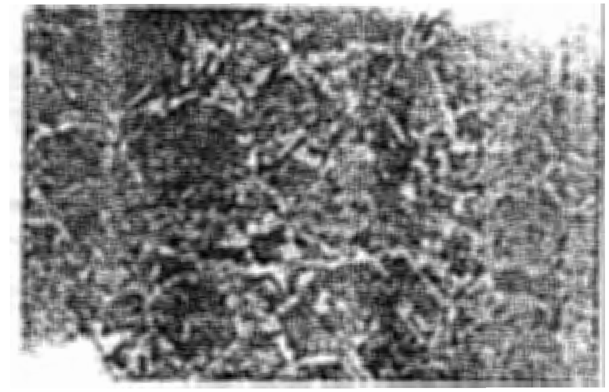


Fig. 6: NST60Mn ~ Heat Treatment at 750°C and Water-Cooled

Fig. 7: NST60Mn ~ Heat Treatment at 900°C and Air-Cooled

Fig. 8: NST60Mn ~ Heat Treatment at 900°C and Oil-Cooled

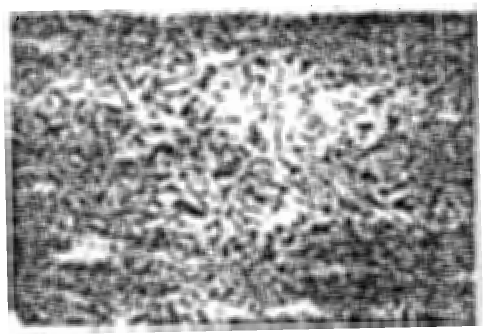


Fig. 9: NST37-2 ~ As-Rolled

hardness compared with the two other cooling media. However, tremendous increase in hardness was noticed in water cooling for both steels.

The steels NST 37-2 and NST 60Mn comprising ferrite-pearlite micro structures form by far the largest category of high strength-low-alloy structure steels. The effects of heat treatment are much more pronounced with water and oil quenching than air cooling. there is a marginal increase in hardness with oil cooling when compared with air cooling. In other words; air cooled steel is more ductile than oil and water cooled samples of the steels. this is in agreement with the observations of other investigators (9). the poor ductilities at faster cooling rates are thought to be due to harder, less ductile ferritic matrix, as a result of excess interstitial carboniferous that are retained in solid solution during rapid cooling.

The amount of total harder phase transformation is increased as the cooling rate increased, and changed from ferrite-pearlite mixtures in most steel on air cooling to martensite at higher cooling rates. As it has been observed (9), the amount of marten site increased more on water cooling than oil cooling. this may account for the little increase in hardness on oil cooling. The micro structures of these steels have indicated that the water cooling samples transformed more into martensite. Table 1, shows the chemical compositions of the steels. Both plain unalloyed steels and conventional HSLA Steels are capable of being treated so that the required phases are obtained. However, the composition must relate to the cooling rate subsequently applied to the partial austenitization and to the required mechanical properties: silicon, besides increasing the hardenability, gives rise to a favourable combination of UTS and elongation, its presence in most steels is beneficial. Manganese confers depth of hardening, but also a particular liability to crack in quenching, for which reason high carbon steels, intended to be quenched in water, should contain less than 0.5%. Manganese raises the yield point and impact values. Manganese can dissolve in ferrite (solid solution strengthen) and form Mn_3C, MnS, MnO and Manganese silicates. Recently, the influence of MnS on ductility of steels has been investigated (10). In their report, it showed that increasing the sulphur content was also accompanied by grain refinement. However, any improvement in the ductility associated with this refinement was offset by the detrimental effect of having a greater volume fraction of MnS inclusions at the boundaries, thereby promoting grain boundary sliding and cavitation. Although this effect has not been studied in these steels, the precipitate of MnS, may somehow increase the ductility, and offset the hardness.

Steels with less than 0.3% carbon cannot be hardened effectively, while the maximum effect is obtained at about 0.7% carbon (7). In steel NST 37-2 the carbon content was less than 0.3%., it can be deduced that about 80% ferrite and 20% pearlite are formed in this steel, invariably have effect on the hardness. While on the other hand, if steels contain about 0.5 and 0.87% of carbon content, the formation of pearlite will be 60 and 100% respectively. Any further increase in carbon gives rise to free commentate at the grain boundaries or as needles (7). The austenitizing temperature should be about 50°C above A_3. However, if a steel containing for example 0.20% C is heat treated at a temperature 50°C below A_3, i.e. at 800°C, the steel containing about 0.4% carbon, on quenching in water the steel will contain 50% ferrite and about 50% martensite (11). Looking at the results of the quenching media of these steels, oil quenching has not raised the hardness significantly. this implies that where hardness can be sacrificed, oil quenching is used. The quenching velocity of oil is much less than water, ferrite and troosite are formed even in small section (7). Troosite is softer than martensite, and small amounts in the steels lessen the risks of cracking and distortion.

Even though small amount of martensite may also form, coupled with the effect of carbon content in these steels this formation cannot give much increase in the hardness of oil quenching when compared to water quenched samples. This has been demonstrated in the results of this work.

The tremendous increases in hardness of these steels (NST60Mn and NST 37-2) at these various heat treatment temperatures and cooling media, are attributed to two major factors, which are the martensitic transformation and

the precipitation hardening of carbides on the grain boundary. The micro structures of these steels have revealed these two phenomena to be responsible for the strengthening of these steels at these treatments. The martensitic transformation which accompany water quenching in these steels, has played the same role of strengthening as the strain induced martensite which was observed during deformation meta-stable alloy (fe-Mn-Mo) recently (12).

In ferrite-pearlite steels the observations that grain refinement benefits both yield strength and the ductile to cleavage fracture transition temperature (13-14), and that there is an additional gain in strength as a result of precipitation hardening by micro alloying (15).

Even though these steels have not been allowed, the precipitation of carbides at the grain boundary, have taken the role of microalloying. Recently, the effect of precipitates of strength and toughness of vanadium strcutural steels were studied (16). It was observed that the rapid cooling rate which results to precipitation of vanadium carbide contributed more to yield strength. these additions contribution to an increase in strength, partly by precipitation hardening due to carbides Fe_3C and partly by martensitic transformation have opened way for further developments of these steels into HSLA and dual-phases. This will help greatly in our automotive industry and other related industries.

The technological importance of these results in this era of Structural Adjustment program (SAP) ARE: NST 37-2 has wide applications in industry where ductilities are necessary. this will depend on temperature of heat treatment and quenching media. On other hand, NST-60-Mn, showed to be a candidate steel for further development into wear-resistant applications especially in agricultural and mining sector.

The small-scale industries can be encouraged to use this simple heat treatment method to produce surface wear-resistance on NST60Mn. Where hardness is to be sacrificed for ductilities, oil quenching can be used.

Conclusion

1. Water seems to be most efficient quenching media where maximum hardness is required but it is liable to cause distortion and cracking of the article.

2. Where hardness can be sacrificed oils such as mineral oil can be used for quenching. Adequate ductility may be obtained.

3. NST 60Mn Steel, with higher Mn and carbon content shows greater hardness at fast cooling rate due to the greater amount of martensitic transformation and precipitation hardening of carbides (Fe_3C)

The air-cooled samples, have not shown much increase in hardness, because the steels transform into ferrite-pearlite, and possibly little of martensite.

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References

1. Lejcek, P., Kadeckova, S., and Raidar, V., "Annealing Processes-Recovery, Recrystallization and Grain Growth, proc. 7th RISQ Int. Symp. (Ed. hansen, N., et al), Roskilde, RISQ National Laboratory, 1986, pp. 437-443.

2. Ralph, B., "Grain growth", materials Science and Technology, 1990, Vol. 6, pp. 113-114.

3. Barlow, C. Y. and Ralph, B., "Structure produced by Rapid Solidification Technology", Metallography, 1985, Vol. 18, pp. 171-177.

4. Hansen, N. and Ralph, B., "The Strain and Grain Size Dependence of Flow Stress of Copper", metals, 1982. Vol. 30. pp 411-417.

5. Dunn, C. G. and Walter, J. L., "Recrystallization, Grain Growth and Texture" Metal park. Ohio, American Society for Metals., 1965, p. 461-469.

6. Honeycomb,R.W.K., "Steels, Micro structure, and Properties, Edward Arnold, first Edition, 1987, chapter 4.

7. Rollason, E. C., "Metallurgy for Engineers", Edward Arnold, Fourth Edition, 1984, chapter 10.

8. Inegbenebor, a. O. Quality, Strength and Standard for Nigerian Steel and petrochemical products, Nigerian society of Engineers, Kano (Dec. 1984) Meeting.

9. Hansen S. S. and Pradham, R. R., "Structure/property Relations in C-Mn-Si. In Dual-Phase Steel". (Eds, Kot, R.A./ and Morris, J.W.), TMS-AIME, Warrendale, PA., 1980, pp. 113-123.

10. Mintz, B. and Mohammed, Z., "Influence of Manganese and sulphur on Hot ductility of Steels, Materials Science Technology. 1989, vol. 5, 1212-1219.

11. Thelning, K. E., "Steel and It's Heat Treatment", Butter-Works, Second Edition, 1984, chapter 6.

12. Inegbenebor, A. O., Jones, R. d. and Ralph, B., "mechanical Properties and Strain-Induced Phase Transformations of Some High Strength Manganese", Journal of materials Science, 1989, vol. 24, pp. 3529-3539.

13. Petch. N. J., "Relationship between Yield Stree and Grain Size", Journal. Iron Steel Inst. London, 1953, vol. 173, pp. 25-32.

14. Petch, J. J., "The Plastic Deformation of Polycrystalline Aggregates", Phil. Mag., 1962, Vol. 7, pp. 45-51.

15. Morrison, W. B., "The effect of Grain Size on the Stress-Strain Relationship in Low-Carbon Steel', Transactions of the ASM, 1966, Vol. 59, pp. 825-845.

16. Bepari, M. M. a., Effects of precipitation on Strength and toughness of Vanadium Structural Steels", Materials Science and Technology, 190, Vol. 6, pp. 338-348.

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