EFFECTS OF QUENCHING AND NORMALIZING ON THE TENSILE TEST PARAMETERS OF MECHANICAL PROPERTIES OF NIGERIAN STEEL NST 60MN

BY

A. O. INEGBENEBOR

DEPARTMENT OF MECHANICAL ENGINEERING
UNIVERSITY OF MAIDUGURI, MAIDUGURI, BORNO STATE

ABSTRACTS

The steel NST 60Mn is popular among the indigenous steel produced and used in the construction industry in as rolled condition. However, it is necessary to know the effect of quenching and normalising on the tensile test parameters of mechanical properties including the work-hardening behaviour of this steel. Such knowledge would assist in using this steel in other manufacturing sectors. From the study, the results show that the normalized samples have higher ductility than the quenched ones. This has been attributed to the transformation to ferrite and little of pearlite phases during normalisation. However, the transformation into the martensitic and precipitation hardening of carbide (fe_3c) are responsible for the improvement of the yield and tensile strength of the steel. This transformation invariably affected the ductile properties of the steel when it was quenched in water. The work-hardening behaviour is explained in terms of dislocation-dislocation interaction. The technological importance of the results obtained are discussed.

INTRODUCTION

Design and manufacturing engineers cannot achieve their aims in engineering without knowing the mechanical properties of the metals they are dealing with As Nigeria has joined the league of steel producing countries, the mechanical properties of these steels would be of interest to both design and manufacturing engineers. The carbon steels produced in the country at present are mainly being used in the construction industry. The steel NST 60 Mn happens to be popular among the other steels produced locally in the construction industry, as they are being used only in as-rolled condition. In exploring the heat-treatment condition of this steel, it is desirable to know what are the benefits that can be derived for our manufacturing industries. 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 defect structure [1].

The conditions that precede the heat-treatment are quenching and normalizing. As steels are heated to upper critical temperature range, the phase diagram shows that the stable structure will be austenite, also known as Gamma phase, which has an FCC structure [2]. Depending on how rapidly this phase is cooled to room temperature, a variety of distribution phases can be produced [3]. When steel is quenched, usually in water or oil, cooling rate is so fast that carbon diffusion and ferrite formation are completely prevented. This results in the formation of a structure known as the martensite, which is a supersaturated solution of carbon in BCC iron. The effect of the supersaturation is to distort the structure to a body centered tetragonal structure [2] and is very hard and brittle. The structure is under considerable internal stress and is unsuitable because distortion arises and therefore care must be taken to reduce the severity of the quench as much as possible. This is achieved through tempering, which consists of re-heating the quenched, fully martensitic steel to a temperature below the lower critical point for the purpose of modifying the structure and relieving the internal stresses. The tempering temperature is the dominant factor affecting the properties of the hardened and tempered steel. [3]

In general, as the tempering temperature is increased, ductility and toughness are developed with some sacrifice in strength and hardness. Hence, compromises can be made and realistic combinations of properties achieved [4]. However, tempering was not done in this study.

In case of normalising, this is a similar operation to annealing in that the metal is heated above the lower-critical line and the carbon goes into solution in the austenite that is so formed. Instead of cooling in the furnace, however, the steel is withdrawn and allowed to cool in still air. This cooling rate is too fast to allow complete carbon diffusion and a much finer grain size is produced since ferrite and pearlite crystals are formed at the smae time [4]. However, the scale of the structure will be somewhat finer than for full annealing. Many medium carbon steels are put into service in this condition, since it is a relatively simple heat-treatment operation and produces a good balance of properties [5].

These types of treatments are very important in producing hard and ductile steels that can be used in our manufacturing industries

The aim of this work is to examine the effect of quenching and normalising on the tensile test parameters of NST 60 Mn. The result would provide awareness of the tensile test parameters of mechanical properties of this steel that can be derived from the conditions of quenching and normalizing after heat-treatment.

Results could also be beneficial to small-scale industries which may use these conditions after heat-treatment as a secondary process to fabricate this steel into various components.

EXPERIMENTAL PROCEDURE:-

The NST 60Mn (was supplied by Jos Steel Rolling Company).

Table 1, shows the composition of the NST Mn steel used in this work. The specimens were prepared in accordance with ASTM E21 - 83. Eight sets of specimens were heat-treated at 750°C, 850°C 900°C and 950°C for one hour and some were quenched in water and normalized in still air. Tensile tests were carried out on a Tinius Olsen Universal tensile testing machine, on each of the samples in a direction perpendicular to the direction of rolling.

The strain rate was 0.04 per minute. For each sample the ultimate tensile strength (UTS), the percentage elongation at fracture, the reduction in the area and work hardening exponent were calculated from the stress-strain curve.

RESULTS AND DISCUSSION

The entire true stress-true strain curve can be accurately expressed as: = $\sigma = k\epsilon^{n}$
where σ is the true stress, k the strength coefficient, ϵ the true strain and "n" the work-hardening exponent. It is applied only in the region of uniform plastic strain of the curve. The value of "n" is the slope of a log true stress - log true strain plot, and the magnitude of "n" is an indication of the stretchability of low-carbon steel sheets [6].

A statistical programme of regression analysis was used in evaluating the work-hardening exponent and strength coefficient (see Table 4). The correlation coefficient is high about 0.98960 for almost all the graphs. There is a clear and conspicuous yield point on the normalized graphs, (see Figure 1-3) of the load and extension graphs, there is not yield point on the quenched graphs. However, to be able to determine the yield strength of the quenched specimens from the graphs, a 0.02% proof stress was used to evaluate the yield strength. It was noted that the yield strength of the quenched specimens are much higher than those of the normalized specimens. Also, from the graphs, the ultimate tensile strength (UTS) for both the normalized and quenched specimens were determined and evaluated. The values showed that the ultimate tensile strength for the quenched specimens are higher than those for the normalized ones (see Table 2). On the other hand, the specimens' elongations and reduction in the cross-sectional area were calculated according to Dieter [7]. The results showed a higher percentage both in elongation and reduction in area for the normalized specimens than that for the queched specimens (see Table 3).

Meanwhile, all the values of the parameters of the as-rolled specimens are within the same range with those of the normalized.

The results of the evaluated work-hardening exponent "n" showed that the normalized specimens have higher values than for the quenched ones (see Table 4). The values of the yield stress for the normalized and 0.2% proof stress of the quenched revealed almost a uniform decrease in their values with increase in temperature. The Figure (4-8) show the engineering stress/strain and the true stress true strain drawn in the region of the uniform plastic strain. The figures are in agreement with Dieter's work [7]. The effects of quenching and normalising are evident in the results on the tensile test parameters of mechanical properties. The normalised specimens are appeared to be more ductile than the water quenched. This is in agreement with observation of other workers [8]. The poor ductility at faster cooling rates is thought to be due to harder, less ductile ferritic matrix, as a result of excess interstitial carboniferous particles 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 this steel in air cooling to martensite at higher cooling rates as observed recently [9]. This martensite and the precipitation hardening of carbides (Fe_3C) at the grain boundary are thought to be responsible for the increased proof stress and decreased percentage elongation and reduction in area of the tensile test parameters because of its brittleness.

In recent work by Inegbenebor [10] on the hardness of some Nigerian steels, it was shown that the air-cooled samples did not show much increase in hardness because, the steel transforms more into ferrite and very little of pearlite. So the corresponding strength will not be as high because ferrite is a soft phase as has been proved by the results of the yield and ultimate tensile strength of the normalized specimens with the quenched ones.

The work-hardening processes of this steel could be explained as follows. During the tensile test at room temperature, as the strain of deformation increases, the dislocation becomes more irregular and interactions of dislocations of different Burgers vectors occur. These add to the assistance in strengthening the steel. However, it has been reported that the work-hardening exponent decreases with increasing concentration of substitutional solutes [11] with decreasing grain size [12], and with increasing volume fractions of second phases [13]. These observations are in agreement with the determined values of "n" in Table 4.

values of "n" in Table 4.

The technological significance of this process is that cooling in water can be adopted to improve strength and hardness of this steel. This could be used in the manufacture of large forging dies, laminated leaf springs for automobile engineering industry, diesel engine liners, hammers and many others.

The high percentage of elongation and reduction in area which agree with the higher values of work-hardening exponent in the normalized as well as rolled-condition, indicated that the steel is ductile. Therefore, it could be used in many manufacturing processes, where the designers of component would prefer a material that displays at least some ductility so that if the applied stress is too high, the component deforms before it breaks. Also a fabricator would need such steel so he can form complicated shapes without breaking the steel in the process.

CONCLUSIONS

1. The tensile test parameters of mechanical properties of the normalized specimens showed higher ductility than the quenched ones.
2. What are responsible for these higher properties have been attributed to the transformation to ferrite and pearlite phases in the steel during normalisation.
3. The transformation into the martensite and precipitation hardening of carbides (Fe_3C) at the grain boundary are responsible for the improvement of the yield and tensile strength of the steel
4. This martensitic transformation has affected the ductility of the quenched specimens in water, because of its hardness and brittleness.
5. The work-hardening processes of this steel has been explained in terms of dislocation-dislocation interaction, which is one of the factors increasing the strength.
6. The effect of the starting temperatures on the properties of the steel were observed on both normalised and quenched steel. However, further work is going on to ascertain the reason behind the effect.

ACKNOWLEDGEMENT

The author likes to thank the Jos Steel Rolling Company, for the supply of the steel. The National Metallurgy Development Centre (NMDC) Jos for the provision of laboratory facilities.

REFERENCE

1. Lejcek, P., Kadeckova, S. and Raiders, V., "Annnealing Processess-Recovery, Recrystallization and Grain Growth, Proc. 7th RISQ Int. Symp. (Ed. Hansen, N., et al), Roskilde, RISQ National Laboratory, 1986, pp. 437-443.
2. Honey Combe, R. W. K. "Steels Microstructure, and Properties"Edward Arnold, First Edition, 1987, chapter 4.
3. Thelning, K. E., Steel and Its "Heat Treatment" Butterworths, Second Edition, 1984. chapter 6.
4. Rollason, E. C. "Metallurgy for Engineers", Edward Arnold, fourth Edition, 1984, chapter 10.
5. Minitz, B. and Mohammed, Z. "Infiuence of Manganense and Sulphur on Hot Ductility of Steels"Materials Science Technology, 1989, Vol. 5. pp.1212-1219.
6. Leslie, W. C. "The Physical Metallurgy of Steels", McGrawHill, New York, 1982, chapter one.
7. Dieter, G. E. 'MECHANICAL metallurgy" 2nd ed. McGraw-Hill, New York, 1976, p. 342.
8. Hansen, S. S. and Pradham, R. R., "Structure/ Property Relations in C-Mn-Si, In Dualphase Steel", (Eds. Kot. R. A. and Morris, J. W.) TMS-AIME, WARRENDALE, P. A., 2980, PP. 113-123.
9. Inegbenebor, A. O. "Heat Treatment of Some Nigerian Constructional Steel and Its Technological Application". Proc. 2nd African - U. S. A. International Conference on Manufacturing Technology, Lagos 1994.
10. Inegbenebor, A. O. "The Effect of Various Heat Treatment on the Hardness of Some Nigerian Steels", (in press) Journal of Engineering Sresearch.
11. Bickwede, D. J. The Effect of Strain Hardening Exponent on Substitutional solutes" Trans. Am. Soc. Met., 1968, Vol. 61 p. 653.
12. Morrison, W. B. The Effect of Grain size on the Stress-Strain Relationship in Low-carbon Steel", Trans. AM. Soc. Met., 1966, Vol. 59. pp. 825-845.
13. Enrietto, J. F., Wells, M. G. H. and Morgan. E. R. "In Precipitation from Iron-Base Alloys" Gordon and Breach, New York, 1965, p.141.

TABLE 1: Chemical Analysis

O	Ni	Mn	P	N	Ni	Cu	AL
0.386	0.161	0.02	0.038	0.006	0.18	0.012	0.003

TABLE 2; Yield Stress and UTS

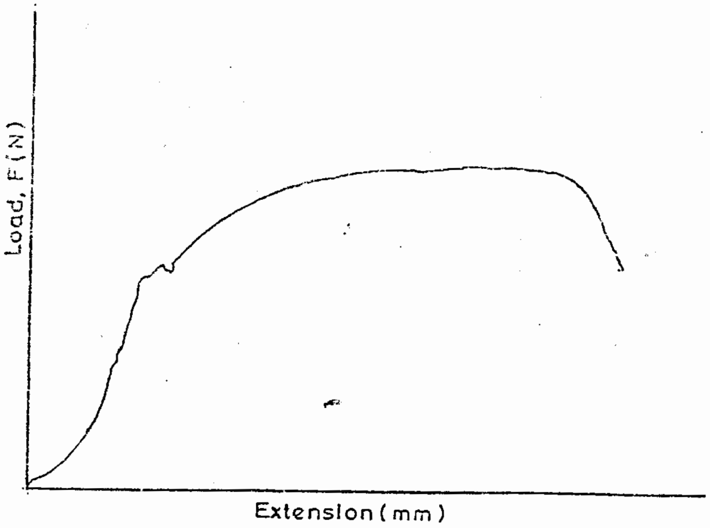
Temperature °C	Normalised		Quenched	
	Yield Stress N/mm^2	UTS N/mm^2	Proof stress N/mm^2	UTS N/mm^2
730	300.44	470.96	509.00	763.28
850	314.80	496.32	568.85	682.08
900	284.20	562.84	559.00	730.15
950	250.84	462.84	533.36	755.16
As-rolled	324.80	503.44		

TABLE 3: Percentage Elongation and Reduction in Area

Temperature °C	Percentage elongation		Percentage Reducation in Area	
	Normalised	Quenched	Normalised	Quenched
750	70.00	37.50	41.18	27.27
850	67.50	39.38	40.30	28.25
900	71.28	29.38	41.60	22.70
950	78.13	31.15	43.86	23.81
As rolled	70.60		41.39	

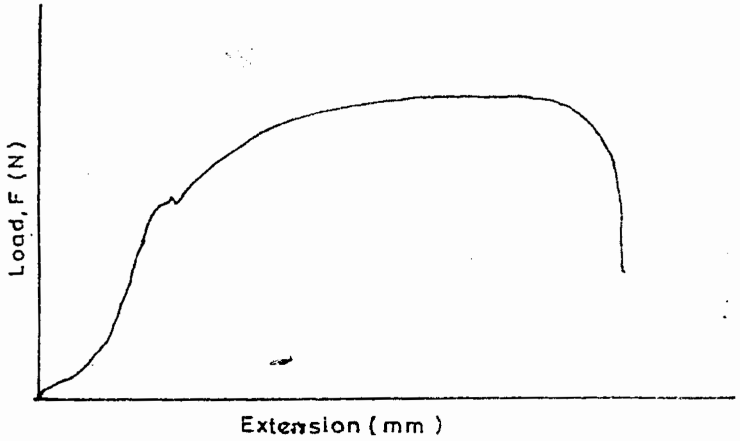
TABLE 4: The Determined Value of "n" and "k"

Temperature °C	Normalised		Quenched	
	"n"	"k"	"n"	"k"
750	0.4512	2.9863	0.2324	3.1135
850	0.4275	2.9807	0.3205	2.95530
900	0.4181	2.9714	0.3306	3.2721
950	0.4771	3.0033	0.1253	3.012
As rolled	0.4133	3.0167		

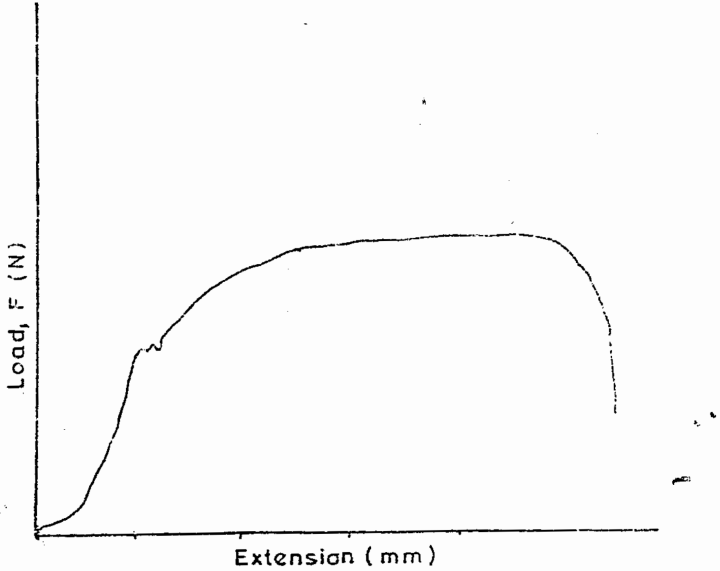


AS = ROLLED

Figure 1: (indicated yield point on the normalized graph of load/extension)

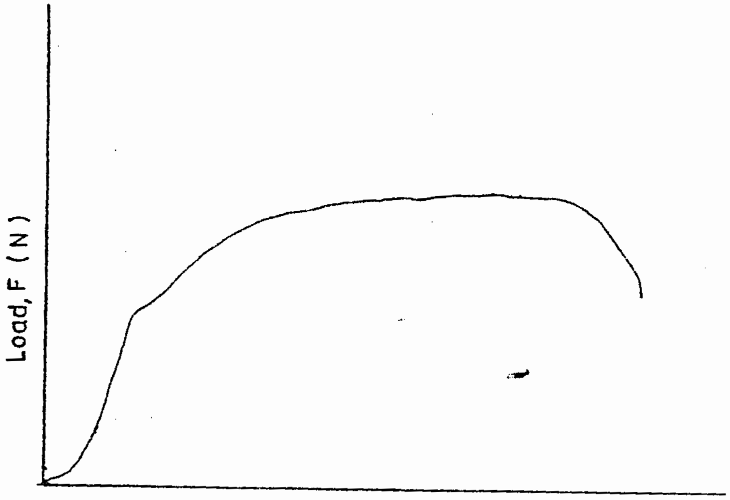


750°c - N = NORMALISED

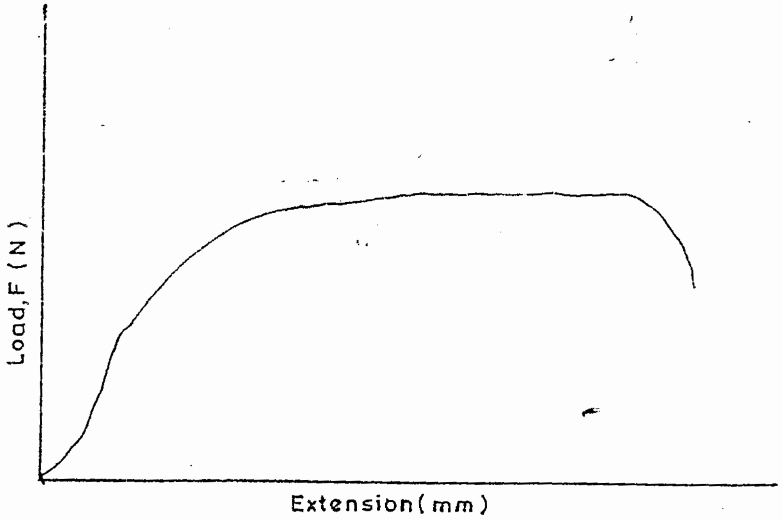


800°c - N = NORMALISED

Figure 2 (indicated yield point on the hormalized graph of load/extension)



900°c - N = NORMALISED



950°c - N = NORMALISED

Figure 3 (indicated yield point on the normalized graph of load/extension)

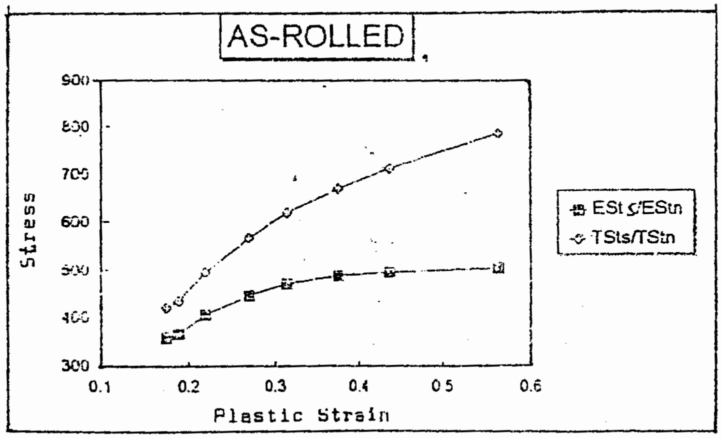
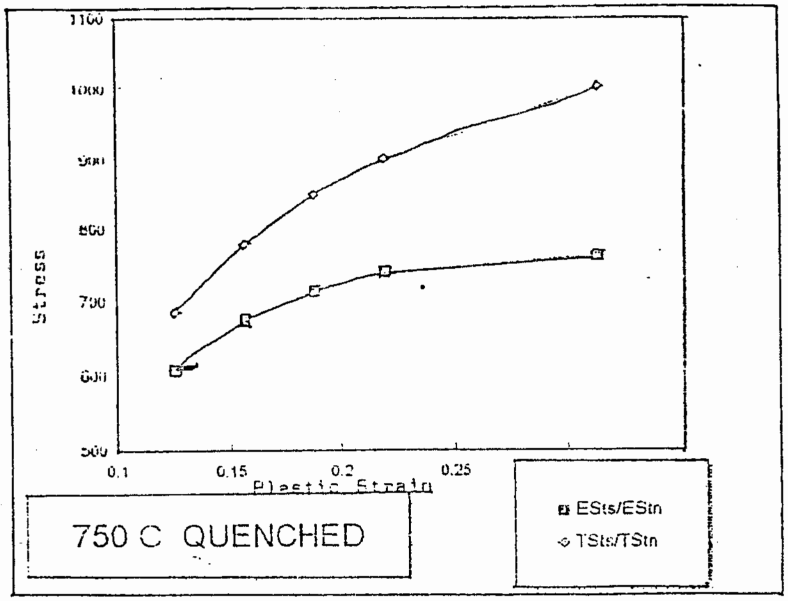


Fig. 4. - AS - ROLLED

Ests - Engineering stress
Estn - Engineering strain
Tsts - True stress
Tstn - True strain



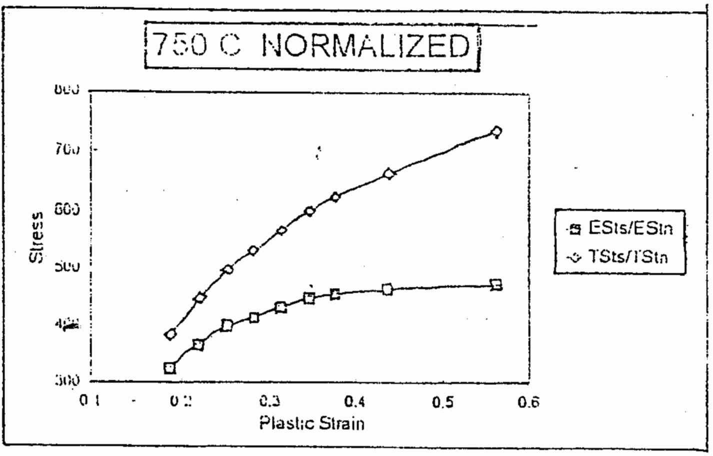
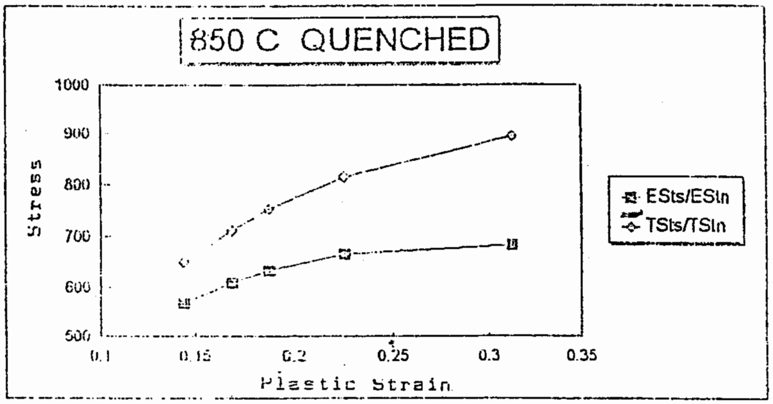


Fig. 5

Ests - Engineering stress
Estn - Engineering strain
Tsts - Ture stress
Tstn - True strain



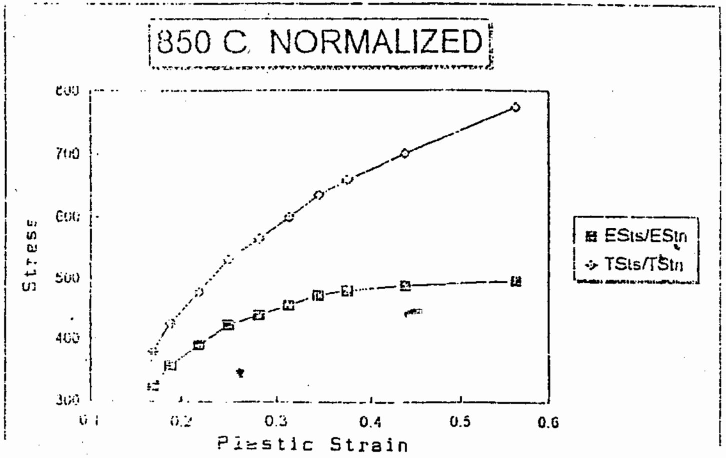
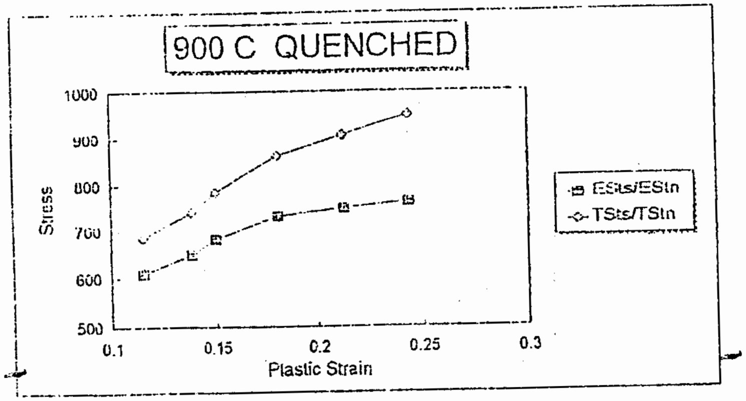


Fig. 6

Ests - Engineering stress
Estn - Engineering strain

Tsts - True stress
Tstn - True strain



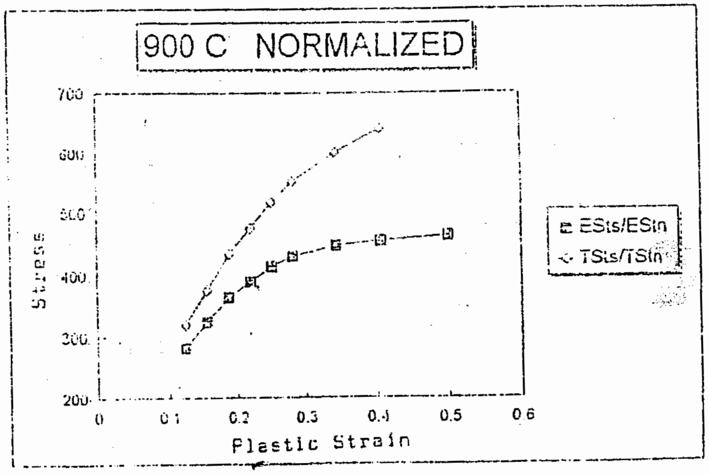
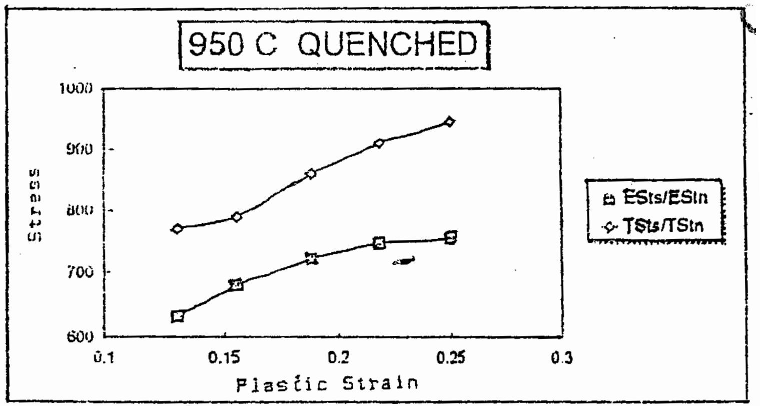


Fig. 7

Ests - Engineering Stress
Estn - Engineering strain

Tsts - True stress
Tstn - True strain



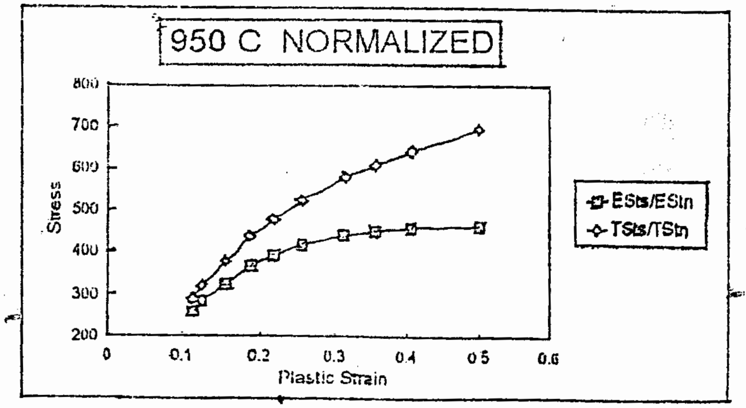


Fig. 8

Ests - Engineering stress
Estn - Engineering strain

Tsts - True stre
Tstn - True stra