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Effects of Initial Grain Size on Recrystalization and Mechanical Properties of Steel

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Absract: The effects of initial grain size on recrystallization and mechanical properties of steel was investigated using mild steel specimens at a different soaking temperature of 750, 850, 950 and 1050°C, respectively at holding time of 10 min for each specimen. The specimens were subjected to both impact test and tensile test to identify the effect of initial grain size on its mechanical properties. It was observed that the value of its initial grain size increases from 17-77 microns as the recrystallization temperature increases from 750-1050°C. It was also observed that the impact strength increased from 21.5-26.55J as the initial grain increases. Also, the percentage elongation and strain increases as the initial grain size increases from 7.7-10.55 and 0.08-0.11% but the values of ultimate stresses and yield stresses decreases from 6.27-5.28 and 4.46-3.70 MN m^{-2} as the initial grain size increase from 17-77 microns.

Key words: Recrystallization, mechanical properties, grain size, steel

INTRODUCTION

Recrystallization: This is the formation of a new set of strain free and equiaxed grains (i.e. having equal dimensions in all direction) having low dislocation density and are characteristic of the pre-cold worked condition. The driving force to produce this new grain structure is the difference in internal energy between strained and unstrained material. The new grains formed, have very small nuclei and growth until they completely replace the parent material, in process that involve short range diffusion.

Also, during recrystallization, mechanical properties that were changed as a result of cold working are restored to their pre-cold worked values. Some heat treatments are designed to allow recrystallization in the mechanical characteristics (William, 1991).

Static recrystallization: Static recrystallization is a hot rolling process, which occurs after deformation. It occurs when the strain per pass is not enough to initiate dynamic recrystallization but exceeding the critical value that is usually determined by prior deformation condition and initial size (Desalu, 2002). The magnitude of the strain has considerable effect on the recrystallization time and the recrystallized grain size. Recrystallization time deceases with increasing strain and the recrystallized grain is refined with an increase in the strain. The ultimate aim in the hot rolling processes is to reduce the grain size to a range of 10-15 μm from an initial grain size which could be in the range of 50-500 μm.This is achieved through a series of rollers, which are spaced apart in such a manner as to get the required result. The study of hot deformation resistance in metals can be use for:

- Designing the mechanical and electrical capacities of hot working facilities.
- Operating hot rolling mills.

Hot strength of steel can be investigated through the use of compression, tensile and torsion tests. Part of the present work aims to highlight through the study of various experimental data, the effects of initial grain size on static recrystallization of steel.

Moreover, during hot rolling process, Sellars (1990) proposed some equations showing the dependence of the critical strain (ϵ^*) and recrystallized grain size (d) on the deformation conditions and initial grain size (do) i.e.

$$\epsilon^* = Ad_o^{0.67} Z^{0.15} \quad (1)$$

Where,

$$Z = \epsilon \exp (Q_{def}/RT)$$

Q_{def} is the activation energy for hot deformation
For recrystallization time (t_{50})

$$T_{50} = Bdo2 \quad (2)$$

Softening by static recovery and recrystallization after deformation takes place with time at rates, which

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depend on the prior deformation conditions and reheat temperature. Static curve follow the Avrami equation, which is given as:

$$X_v = 1-(\exp\{-C\,(t\,/\,t)\}) \qquad (3)$$

Where

X_v : The recrystalized fraction in time t.
t_f : The time some specific fraction will recrystallize.
K : The Avrami`s constant.

$$C = \text{In}\,(1\text{-}f) \qquad (4)$$

Micro structural evolution during hot deformation: Thorough investigation has been carried out in order to correlate the parameters that are used in hot deformation processed and the microstructure that evolves. Foremost on the list of scientific literature works are those of Morgridge (2001), Sellars (1990) and Hodgson *et al*. (1993) etc.

The various equations described the recrystallization process, also the kinetics of grain growth all with major objective of predicting the various microstructures that evolves with different conditions. For each stage in the recrystallization and recovery process, several parameters have been highlighted as being contributors to the determination of the resulting microstructure.

Flow stress: It is always necessary to determine the amount of stress necessary to induce the deserved deformation at the rolling stage (Kuziak, 1997). This is termed flow stress. It is expressed as a function of the Zener-Holloman's parameter Z.

Equation relating the flow stress to the Zener-Holloman's is

$$Z = \exp\,(Q/RT) = A\,(\sinh\,(\propto\sigma)\,)^n \qquad (5)$$

Where

Q : The activation energy.
σ : The flow stress.
A, n, α : Constants.

These are other equations that show significant correlations in the micro structural evolution process. This includes the equation for the recrystallization time and recrystallized volume fraction. The general model for the recrystallized grain size varies for each recrystallization process i.e. Static, Dynamic and Metadynamic.

Hodgson (1993) proposed that the general model for the recrystallized grain size after static recrystallization is:

$$Dr = C_1 + C_2\,\varepsilon^m\,\varepsilon^n\,D^1\exp\,(\text{-}Qd/RT) \qquad (6)$$

Where

C_1, C_2, M, n, I and Q_d are all constants.

MATERIALS AND METHODS

Specimens of diameter 5mm were held for 10 min at different soaking temperature of 750, 850, 950 and 1050°C. The specimens were then water quenched to retain the properties at the specific temperature.

By holding in a Bakelite powder, the specimens were held on a mounting press to form casing. The specimens were subjected to grinding on emery paper of decreasing coarseness followed by polishing using electronics universal polisher and then etched in a natal solution (2 nitric acid and 98% methylated spirit). Through linear analysis using an electronics microscopic arrangement, the grain sizes were measured. The heat treatment gave rise to different grain sizes ranging from 17-77 microns. Standard models were used in calculating various metallurgical parameters.

The specimens were then subjected to impact ant tensile tests to determine the effects of the various grain sizes on them.

RESULTS AND DISCUSSION

The result of the heat treatment shows that as the recrystallization temperature increases, the initial grain size also increases which gave rise to various grain sizes as shown in Table 1 and the graph showing this relashionship is shown in Fig. 1:

Impact test: Impact test was carried out on each of the specimens of the steel at different grain sizes to know it effects on the grain sizes. The energy absorbed in breaking the specimens is a measure of the impact strength of the material. The specimens were matched to determine the propensity of the material to brittle failure.

The result is presented in Table 2 and the graph showing the relationship in Fig. 2.

Table 1: It can be noted that linear relationship exist

Recrystallization temperature (°C)	750	850	950	1050
Grain size (microns)	17	28	52	77

Table 2: Impact test result

Soaking temperature (°C)	Grain size (microns)	Energy (Joules)
750°C	17	21.5
850°C	28	23.4
950°C	52	24.8
1050°C	77	26.5

Table 3: Tensile test result

Grain size (microns)	Diameter (mm)	L1 (mm)	L2 (mm)	L1 -L2	YL (Kn)	UL (Kn)	YS $MN\ m^{-2}$	US $MN\ m^{-2}$	e (%)	Strain
17	5.00	180	194	14	8.75	12.25	4.46	6.25	7.78	0.8
28	5.00	180	196	16	7.95	11.65	4.10	5.94	8.89	0.9
52	5.00	180	197	17.5	7.50	11.30	3.82	5.77	9.72	0.1
77	5.00	180	199	19	7.25	10.35	3.70	5.28	10.55	0.11

L1: Original Length; L2: Elongation; YL: Yield Load; YS: Yield Stress; UL: Ultimate Load; US: Ultimate Stress %e-1 % elongation

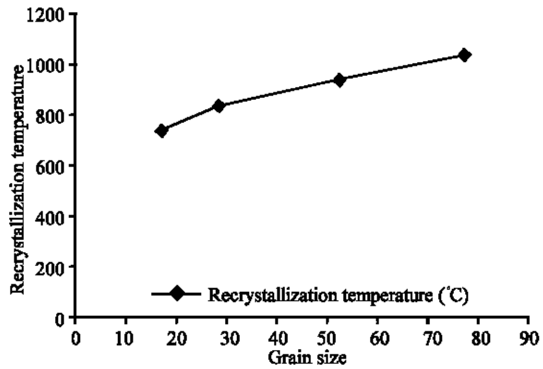

Fig. 1: The graph of recrystallization temperature Vs grain size

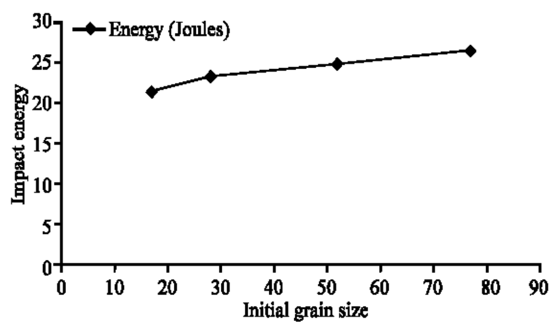

Fig. 2: Impact energy vs initial grain size

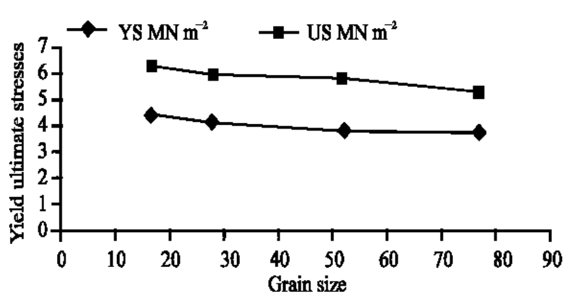

Fig. 3a: Yeild and ultimate tensile streses Vs Initial grain size

Tensile test: Tensile test was also carried out on all the specimens with different grain sizes. Consequently the result was calculated usingr Eq. (3). The results are as presented in Table 3 and Fig. 3a-3c shows the results graphically.

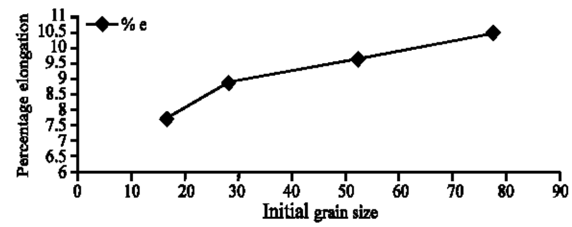

Fig. 3b: Percentage Elongation Vs Initial grain size

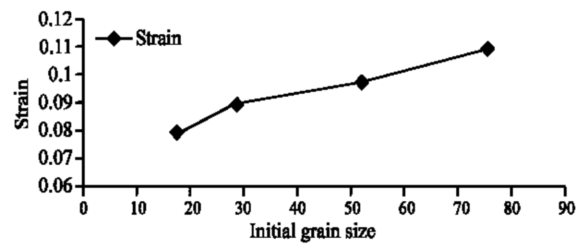

Fig. 3c: Strain Vs initial grain size

CONCLUSION

Experimental studies were carried out to evaluate the effects of initial grain size on static recrystallization of steel. The results from the experiments have actually showed that the values of the initial grain size and temperature have significant effects on tensile strength and impact strength of steel.

For improving the mechanical properties of steel, the initial grain size should be refined.

It can also be inferred from the results that the ultimate stresses decreases as the initial grain size increases.

Similarly, the yield stresses decreases as the initial grain size increases. Impact strength of steel increases as the initial grain size increases. Percentage elongation, which is a measure of ductility, increases as the initial grain size increases.

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