International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 1 | Issue – 6

To Study the Effect of Stress Concentration Factor on Mild Steel due to Heat Treatment

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ABSTRACT

The present work is to study the effect of various types of heat treatment processes on stress concentration factor (Kt) of a plate with a circular hole subjected to a uniform loading. Finite Element Analysis using ABAQUS 6.13-1 has been done in order to calculate, Ktfor rectangular plates with holes of different diameters. Stress-Strain diagrams are generated from standard tensile specimens (ASTM E8) with Universal Testing machine (HEICO), before and after various types of heat treatment process. Young's Modulus, Poisson's Ratio and the Plastic strain verses Stress are calculated from the Stress-strain diagram and feed as an Input parameter for the FEA analysis. The results shows that the value of Kt for quenching has a higher value in comparison to room temperature mild steel specimen and the value of Kt for normalizing and annealing show a lower value in comparison to room temperature mild steel specimen.

Keywords: *Stress Concentration factor (Kt), Heat treatment, Tensile Test, Finite Element Analysis*

NOMENCLATURE

D	Width of specimen (m)
d	Diameter of circular hole (m)
F	Force (N)
T	Thickness of specimen (m)
t	Theoretical
Greek Symbols	
σ	Stress (N m^{-1})
Subscripts	
max	**Maximum**
nom	Nominal

1. INTRODUCTION

The application of mathematical and experimental methods of stress analysis has produced reliable information on values of stress concentration factors for widely different designs. The maximum stress is then obtained by multiplying a factor by the nominal stress. This knowledge of maximum stress can be related to the mechanical properties of the material, and so an estimate of strength can be made. In general, this estimate is not a reliable one, because the ideal homogeneous and elastic material assumed in arriving at the theoretical stress concentration factor does not accurately represent the structural material actually used in practice. This causes observed strength values of notched parts to be equal to or greater than, that which is indicated by the direct application of theoretical stress concentration factors.

Stress concentration is defined as the localization of high stresses due to the irregularities present in the component and abrupt changes of the cross section.
To determine the stress concentration the specimen is subjected to a uniform load for different diameters of hole present in it. Since the area around the hole is less there is a sudden rise in the magnitude of stresses in the vicinity of the hole.

The localized stresses in the neighbourhood of the hole are far greater than the stresses obtained by elementary equations as mentioned in Mechanical Engineering Design [1]. But due to heat treatment the mechanical properties get altered thus the stresses get changed.

Localised stress is being calculated as

$$\sigma_{nom} = \frac{F}{(D-d)T} \quad (1)$$

In order to consider the effect of stress concentration and find out localised stresses, a factor called stress concentration factor is used

The stress concentration factor (K_t) is calculated from the nominal stress σ_{nom} obtained from Eq. (1) and maximum stress σ_{max} from FEA. The stress concentration factor is calculated as

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}} \quad (2)$$

As, K_t is a very important factor in machine design various works have been done on stress concentration by various researchers like Shaik and Mirzana [2] with composite material; sun et al. [3] on upper yield point of mild steel but this work is mainly focused on the change in the nature of K_t on mild steel before and after heat treatment.

2. SPECIMEN
The specimen is made up of mild steel

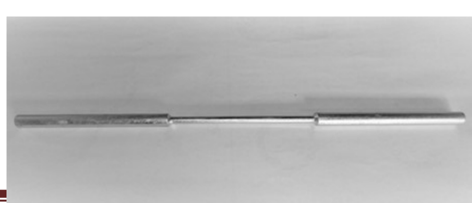

Fig. 1: Tensile test specimen.

The percentage of carbon in mild steel is less which makes it strong and tough but not radially tempered. When the mild steel is heated above its recrystallization temperature, where deformed grains are replaced by a new set of defects-free grains that nucleate and grow until the original grains are entirely consumed due to which the mechanical properties get changed.

3. EXPERIMENTAL PROCEDURE

3.1 Heat treatments
The heat treatments that have been performed in this study are Annealing, Normalising and Quenching[4].

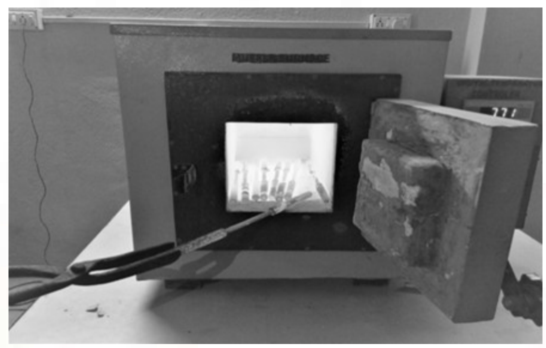

Fig. 2: Heating the tensile test specimens above its transformation temperature.

The tensile test specimens were kept in the furnace 30 degrees above the recrystallization temperature of mild steel which was found to be 880 degree Celsius for 20 minutes shown in fig. 2. For Annealing the tensile test specimen was cooled in the furnace itself by keeping it for 24 hours, for Quenching the specimen was bathed in water pool and for Normalizing it was kept in steady air at room temperature for 4-5 hours.

3.2 Tensile test

The tensile test is performed on the specimen before and after heat treatment in Universal Testing Machine (HEICO) shown in Fig 3.

Fig. 3: Universal Testing Machine (HEICO)

Due to the dual phase strengthening mechanics; the mild steel has a good balance of strength and ductility. The yield stress value for the quenched specimen was observed to be greater than that of normalized and annealed specimens, while the normalized specimen also has a greater value than that of annealed specimen, which has the least value.

Engineering stress/strain was obtained from the tensile test. These values were converted to true stress/strain values by the following Eq. (3) and Eq. (4) [5, 6]

$$\varepsilon_{true} = \ln(1 + \varepsilon_{engineering}) \quad (3)$$

$$\sigma_{true} = \sigma_{engineering}(1 + \varepsilon_{engineering}) \quad (4)$$

The value of ultimate tensile stress were observed to be in the order Quenched> before heat treated>Annealed>Normalized, possibly due to the refinement of the grains at primary phase after the subsequent cooling processes. The ultimate stress and the yield stressof the material after and before heat treatments are enlisted in the Table 1.

Table 1: Yield stress and ultimate stress for different tensile test specimen.

Tensile test specimen	Yield stress (MPa)	Ultimate stress (MPa)
Without heat treatment	307.701	615.403
Quenching	733.805	1386.742
Normalizing	250.457	406.992
Annealing	198.858	423.495

4. FINITE ELEMENT ANALYSIS

Elasto-plastic analysis for different diameter of hole in the specimen is performed using ABAQUS 6.13-1. The material consecutive properties are defined by the Young's modulus and Poisson's ratio, and yield stress verses plastic strain obtained from tensile test data performed at room temperature before and after heat treatment in Universal Testing Machine (HEICO) in Fig. 3. The data obtained from the tensile test are being plotted in the fig. 8, after subtracting the elastic strain from the total strain we get the plastic strain and corresponding plastic stress are obtained.

Three dimensional final modelling of the mild steel plate has been done for a constant thickness of 5mm. The FE model was meshed with 8 node isoperimetric hexahedral elements with 8 Gauss points taken for all calculations. Reduced integration with full Newtonian non-linear analysis computation is carried out for all the specimens. The mesh size is kept 0.9mm throughout the specimen. Since large strain is expected near the circumference of hole, perpendicular to the direction of applied load. Material non linearity is being introduced in the specimen; large strain analysis in the FE model is incorporated. The stress distribution pattern on the plate without heat treatment, Annealing, Normalizing, and Quenching is shown in Fig.4, Fig.5, Fig.6 and Fig.7 respectively.

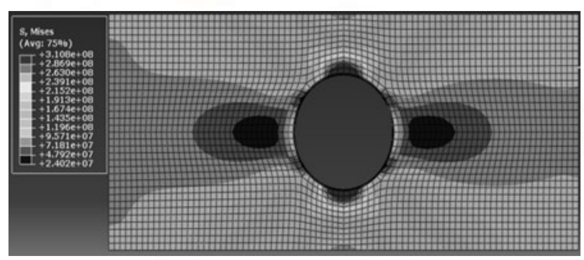

Fig. 4: FEA of the plate with a circular hole of dia.0.015mm without heat treatment.

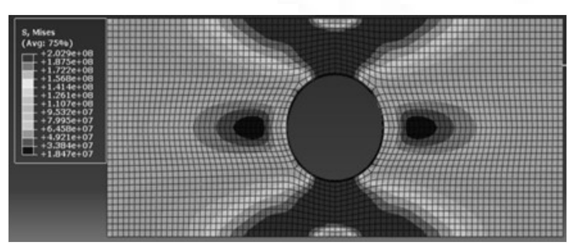

Fig. 5: FEA of the plate with a circular hole of dia.0.015mmafter annealing.

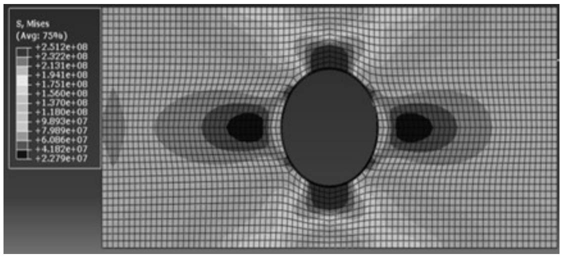

Fig. 6: FEA of the plate with a circular hole of dia.0.015mmafter normalizing.

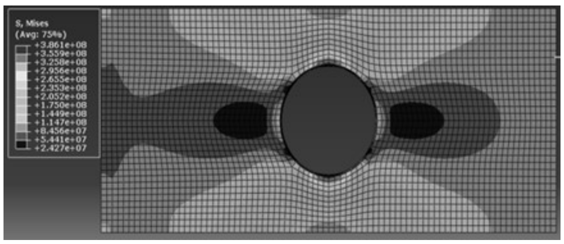

Fig. 7: FEA of the plate with a circular hole of dia.0.015mmafter quenching

Since, after heat treatment the steel changes its properties

5. RESULTS & DISCUSSIONS

5.1 Stress Strain nature of Mild steel

Stress strain curve is the behaviour of material when it is subjected to uniform load. Annealing produce refined microstructure and normalizing provide uniformity in grain size, for which the specimen's hardness gets decreased. Quenching reduce grain size of the specimen, hence making the specimen harder. As stress is a factor of hardness, the stress also gets changed.

The input parameters, Young's modulus are calculated from the slope of the stress strain graph before yield stress and Poisson's ratio is calculated by dividing transverse strain by lateral strain.

This change of stress due to different heat treatments is shown in the fig.8.

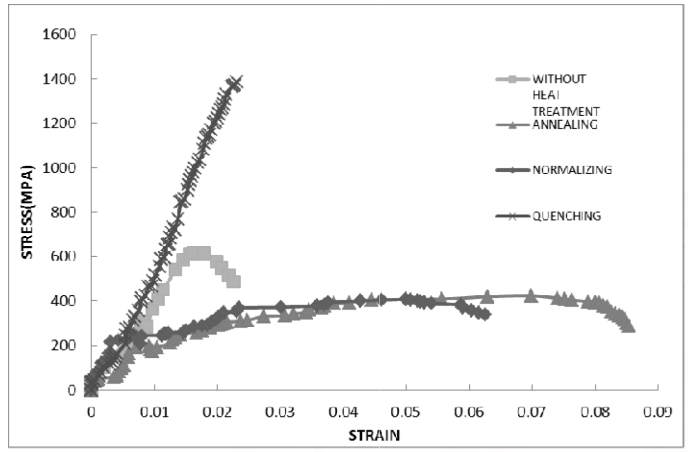

Fig. 8: Stress strain curve before and after different heat treatments.

5.2 Effect of heat treatment on stress concentration factor

The Stress Concentration factor (K_t) obtained from the experiment for different d/D values before and after heat treatment are enlisted in Table 2.After heat treatment due to the transformation of crystals the hardness of mild steel gets changed as stated earlier. Stress concentration factor being a factor of stress, also gets changed.

Table 2: Stress concentration factor for different values of d/D

d/D	K_t			
	Without heat treatment	**Annealing**	**Normalizing**	**Quenching**
5/30	1.82	1.659	1.79	1.79
10/30	1.96	1.331	1.67	1.96
15/30	1.554	1.046	1.26	1.931
20/30	1.096	1.112	0.96	1.817
25/30	1.026	0.676	0.677	1.238

Due to heat treatment there is a change in stress of the material as observed in fig.8, thus the stress concentration factor also gets altered. For annealing and normalizing due to uniformity of crystal structure stress generated in the specimen is less than stress generated in normal specimen. In quenching due to the formation of finer grains, stress generated in the specimen is comparatively less than normal specimen.

Hence, stress concentration factor varies. This change of the nature of K_t with d/D are being plotted in the Fig. 9 before and the heat treatment processes.

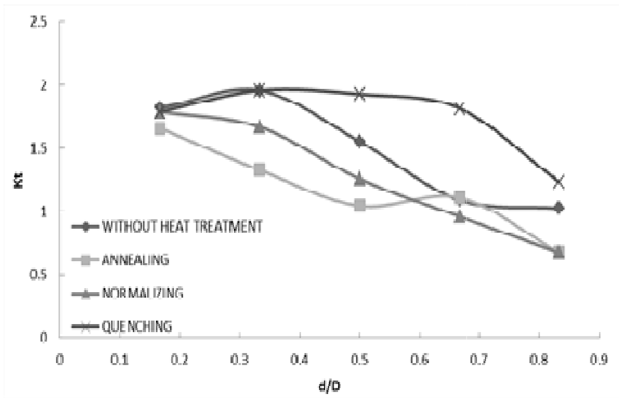

Fig. 9: Stress concentration factor of mild steel before and after heat treatment.

CONCLUSION

From the results obtained from the experiment, it can be concluded that mechanical properties depends mainly on the various heat treatment and cooling rate. Thus, depending upon the application proper heat treatment should be adopted. Since, for annealed metal K_t is low hence it should be used for high ductility and minimum toughness. Whereas for maximum hardness normalizing the carbon steel will give the satisfactory result, as K_t is maximum.

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