Prediction of quench severity of various quench media based on hardness and microstructure studies

Vivek Tiwary*
Asst Professor
IP & E Dept
GIT, Belgaum
Vgtiwary@git.edu

Adarsh Patil
Asst Professor
Mechanical Dept
BVBCET, Hubli,
adarsh.ptl@gmail.com

Zuber Mulla
IP & E Dept
GIT, Belgaum
gitzuber@gmail.com

Chandrashekhar I. Bha
IP & E Dept
GIT, Belgaum
chandrashekhar.bhavikatti76@gmail.com

Abstract— An investigation was conducted to characterize quenchants based upon their quench severities for heat treatment purposes. The study involved quenching steel samples in different quench media and determining the hardness number and microstructure using SEM. By comparing the hardness numbers and the microstructures obtained it can be predicted that brine solution gives highest quench severity when compared to distilled water or oil. The same samples when tempered resulted in decrement of hardness values. The main aim of this work was to characterize quenchants based on hardness number, microstructure evolved and also an effort was made to know the effects of tempering on the quenched steel samples.

Keywords—Quenching, Tempering, Hardness, Heat Treatment, SEM, Quench Severity

I. INTRODUCTION

Heat treatment is a tool by which the mechanical properties of metals and alloys can be altered to suit our requirement. Quenching, as one of the most important method of heat treatment, can improve the performance of metals and alloys greatly. Quenching of steel involves the process of heating a part to austenitizing temperature, holding at this temperature for a specified time followed by intense cooling in a suitable quench medium. Quenching prevents the formation of ferrite or pearlite and allows the formation of bainite or martensite. The effectiveness of quenching depends on the cooling characteristics of the quenching medium and the ability of the steel to harden. Attaining desired hardness, strength or toughness and minimising the undesired residual stresses are the key indicators of successful quenching process [1]. Quenching of steel in liquid medium consists of three distinct stages of cooling: the vapour phase stage; nucleate boiling stage; and convective stage as shown in the Fig 1. In the first stage, as the name suggests, a blanket of quenchant vapours forms over the specimen surface. This avoids physical contact of specimen with the liquid quenchant. This vapour blanket has an insulating effect, and heat transfer in this stage is mostly through radiation. As the temperature drops, the vapour blanket becomes unstable and collapses, initiating the nucleate boiling stage. Nucleation and collapse of bubbles at the specimen surface causes turbulence at the surface, improving convective heat transfer rates. Heat removal is the fastest in this stage, and continues till the surface temperature drops below the boiling point of quench medium. Further cooling takes place mostly through convection and conduction [2]. The performance of a quenchant can be expressed by measuring the hardness of the quenched body. Although quenching results in high hardness values, one of the major drawbacks associated with quenching is distortion and development of internal stresses, especially in steel specimens [3]. One of the key factors in quenching is to select a quench media which gives optimum mechanical properties with least amount of distortion and internal stresses [4]. In the present work, an attempt is being made to characterize the quench media based on the hardness values and microstructure it produces.

Tempering is the process of heating hardened steels to below the lower critical temperature to achieve some softening, and then cooling the steel back to room temperature. The objective of tempering treatment is to relieve some internal stress and to reduce hardness, thereby creating higher ductility than is possible in as quenched parts. Tempering slightly modifies the structure of martensite, and this change can be used to adjust strength, hardness, toughness, and other mechanical properties to specified levels [2]. Hence the present work is carried out with the following objectives:

- Evaluating the quench severity of different quench media based on its hardening power and microstructure developed.
- Evaluate the effect of tempering on the quenched samples.

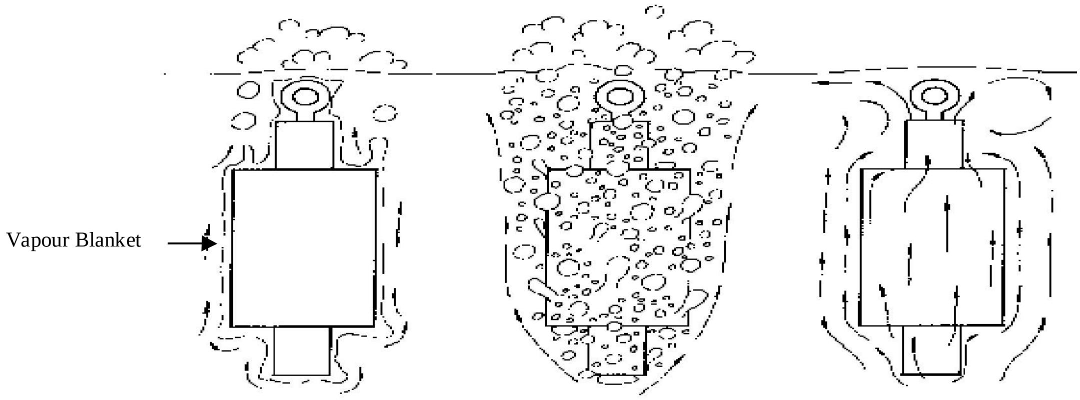

Fig 1 the stages of cooling during quenching of a steel specimen

II. EXPERIMENTAL WORK

12.5 mm *Φ* cylindrical steel bars having 0.46 carbon percentage (medium carbon steel) were procured from the local market. The cylindrical bar was cut to 30 mm length using power hack saw to make several samples. The samples were polished, etched in Nital 5% solution and SEM images were taken. Hardness number was determined by Rockwell machine 'C' scale. Distilled water, SAE20W40 engine oil and 10% strength brine solution was selected as the quenching media. Two litres of the above mentioned quenchants were taken. The steel samples were heated in a muffle furnace to 850 ^{0}C (Austenitizing temperature), held for 15 min and then quenched in different quench media. Hardness number and SEM images were taken after quenching. The same samples were tempered at 400^{0}C. SEM images as well as hardness were again determined after tempering. Hardness values of the raw samples, quenched samples and tempered samples were compared. Also the microstructure of the raw samples, as quenched samples and tempered samples were compared.

III. RESULTS AND DISCUSSION

Hardness numbers were determined for the raw samples, quenched samples in different media as well as for the tempered samples. The results are as shown in table I. It can be observed that brine quenching resulted in maximum hardness. The reason is attributed to the Na^+ and Cl^- ions destabilising the vapour blanket that is formed around the samples during the first stage of cooling and hence resulting in maximum heat removal and maximum hardness value. Water quenching and oil quenching also showed increment in hardness values. Further, tempering resulted in decrement of the hardness values that were obtained after quenching the samples.

TABLE I
HARDNESS NUMBER OF THE AS RECEIVED STEEL SPECIMEN

Heat Treatment Process	**10% Brine**	**Distilled water**	**Oil**
Quenching	54	52	27
Quenching + Tempering	42	36	21
Raw Sample	16		

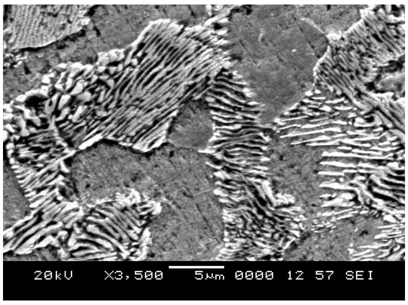

Fig 2 Microstructure of as received steel sample

Microstructural analysis was carried out using SEM. Microstructure of the as received sample is shown in the fig 2. Mictrostructure revealed typical pearlite grains made up of alternate lamella of cementite and ferrite. Quenching results in transformation of pearlite structure to martensite and retained austenite. Microstucture evolved after quenching in brine, water and oil is as shown in fig 3, 4, 5 respectively. Brine quenched samples showed highest percentage of martensite. Water quenched samples showed intermediate martensite percentage while oil quenched samples showed the least percentage of martensite. Tempering results in transforming of martensite that are formed during quenching into other phases like ferrite and cementite. Microstructure evolved after tempering the quenched samples at 400^{0}C are as shown in fig 6, 7 and 8. The amount of transformed martensite was highest in case of water quenched+tempered samples, intermediate in case of brine quenched+tempered samples and least in case of oil quenched+tempered sample.

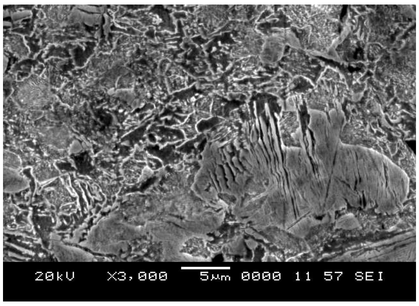

Fig 3 Microstructure of Brine quenched Steel sample

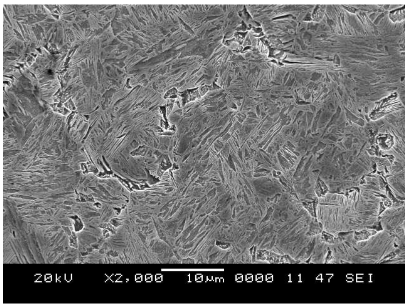

Fig 4 Microstructure of Water quenched Steel sample

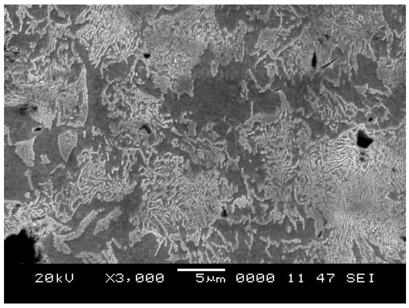

Fig 5 Microstructure of Oil quenched Steel sample

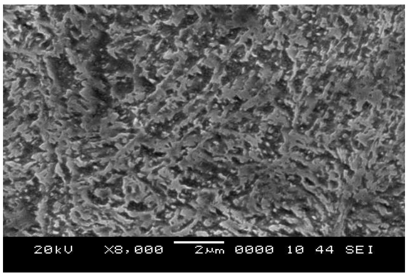

Fig 6 Microstructure of Brine Quenched +Tempered steel Samples

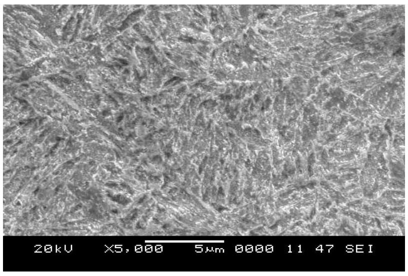

Fig 7 Microstructure of Water Quenched+Tempered steel Samples

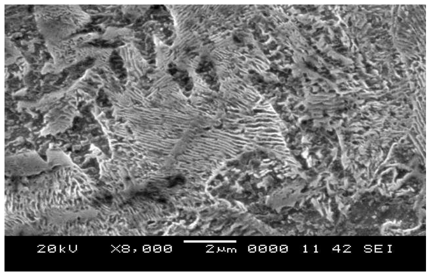

Fig 8 Microstructure of Oil Quenched+ Tempered steel samples

The hardness numbers obtained after quenching and tempering the samples were plotted and the same is shown in fig 9. Based on the hardness number and the amount of martensite obtained we can predict the quench severities of the subject quenchants. It can be observed that brine quenching gives the highest hardness value and martensite phase and hence can be predicted that it has the highest quench severity. Water gave intermediate hardness value and martensite phase and hence we can predict its quench severity also to be intermediate while oil gave the least hardness and martensite phase and hence has the lowest quench severity. Therefore based on the hardness number as well as the amount of martensite phase we can predict the quench severity of the subject quenchant in the descending order as Brine solution > Water > Oil.

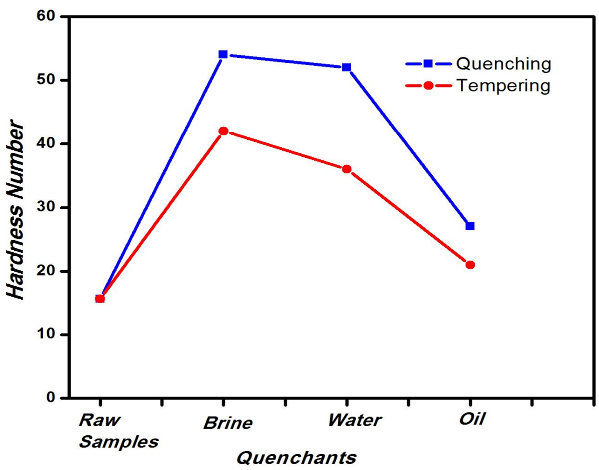

Fig 9 Hardness Number vs Quenchants

IV. CONCLUSIONS

Quench severities can be predicted by comparing the hardness number and microstructure evolution. In the present investigation, the quenched severity is predicted based on the hardness number and the amount of martensite phase evolved and can be arranged in the descending order as Brine>Water>Oil. Tempering results in decrement of hardness level because of the transformation of martensite into other phases like ferrite and cementite.

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