IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727
PP 96-101
www.iosrjournals.org

Influence of Tempering Temperature on Mechanical Properties and Microstructure of EN 24 Steel

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Abstract: *The paper presents results of research on the influence of tempering temperature on microstructure and mechanical properties of EN-24 steel. Tempering of the investigated steel was carried out at the temperatures of 580^{0}C, 610^{0}C, 650 ^{0}C. After tempering the cast steels were characterized by a structure of tempered lower bainite with numerous precipitations of carbides. Performed research of mechanical properties has shown that high temperatures of tempering do not cause decrease of mechanical properties beneath the required minimum. The investigation also reveals that the hardened samples give the highest hardness and strength values while highest hardness and strength values for the tempered samples was obtained at temperature of 580°C. So 580°C was found to be an optimum temperature for well balanced mechanical properties of EN -24 steel.*

Keywords: *Heat Treatment, tempering temperature, Mechanical Properties, martensite , EN-24 steel*

I. Introduction

The process of heat treatment involves the use of heating or cooling, usually to extreme temperatures to achieve the wanted result. It is very important manufacturing processes that can not only help manufacturing process but can also improve product performance, and its characteristics in many ways.

Untempered EN-24 steels, while very hard are too brittle to be useful for most applications. Most applications require that quenched part be tempered, so as to impact some toughness and further improve ductility. Current work reports and analyzes results of mechanical testing was performed on EN-24 steel samples, to arrive at an optimum heat treatment strategy for judicious combination of hardness and tensile properties. Tensile and hardness test specimens were fabricated using Lathe machine. These samples were subjected to various heat treatment sequences, consisting of stress relieving, hardening, oil quenching, and tempering at different temperatures. Heat treated samples were then mechanically tested for hardness (Rockwell) and tensile properties (yield stress, ultimate tensile strength, % elongation. % reduction in area).

II. Material for research

Material for research was EN-24 steel. Samples for investigation has chemical composition presented in Table 1.

Table 1

Test Result OfEN - 24

Sl.No.	Tests	Actual	Specified	UOM
1	CARBON	0.35002	0	%
2	SILICON	0.27409	0	%
3	MANGANESE	0.54899	0	%
4	SULPHUR	0.02929	0	%
5	PHOSPHORUS	0.03572	0	%
6	NICKEL	1.42715	0	%
7	MOLY	0.19251	0	%
8	CROMIUM	0.92244	0	%
9	COPPER	0.09420	0	%
10	TITANIUM	0.00143	0	%
11	ALUMINIUM	0.01600	0	%
12	FE	96.02338	0	%

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III. Methodology of research

Standard tensile and hardness test specimens of 25 mm diameter each were made from EN-24 steel in collaboration with a lathe machine. Samples were subjected to different heat treatment sequences: stress relieving, hardening, oil quenching, and tempering at three different temperatures: 580^0C, 610^0C, 650 ^{0}C. Heat treated specimens were mechanically tested for yield stress, ultimate tensile strength, % elongation. % reduction in area.

A) Heat Treatment

Prepared test samples were heated to relieve stress at 550°C, soaked for 1 hr using a muffle furnace and then cooled in air. The test samples then hardened by heating at 850°C , soaking for 90 min and and quenched in oil (temperature below 80°C) for 20 min. Tempering treatment was conducted immediately on all three hardened and quenched samples at different temperatures of 580^0C, 610^0C, 650 ^{0}C with dwell time 1 hr in the furnace environment and allowed it to cooled in air to room temperature.

B) Mechanical Testing

Mechanical tests were conducted on untreated, as-hardened and hardened-tempered samples to evaluate their tensile and hardness properties. A Rockwell type digital microhardness testing machine was used to conduct the hardness test measurements. Hardness values were determined by taking the average of five HRC readings at different positions on the test samples. Similarly, tensile test was conducted on untreated and hardened-tempered samples at room temperature using a 600kN Avery-Denison universal testing Machine. The ends of the specimen were gripped in the machine, and load was applied until failure occurred. The initial gauge length and diameter were measured before subjecting them to tension. The yield and maximum loads were recorded directly from the resulted graph, the broken ends of each of the specimens were fitted and the final gauge length and also the smallest diameter of the local neck were measured. The readings thus obtained were used in the determination of the yield strength, ultimate tensile strength, percentage elongation (ductility).

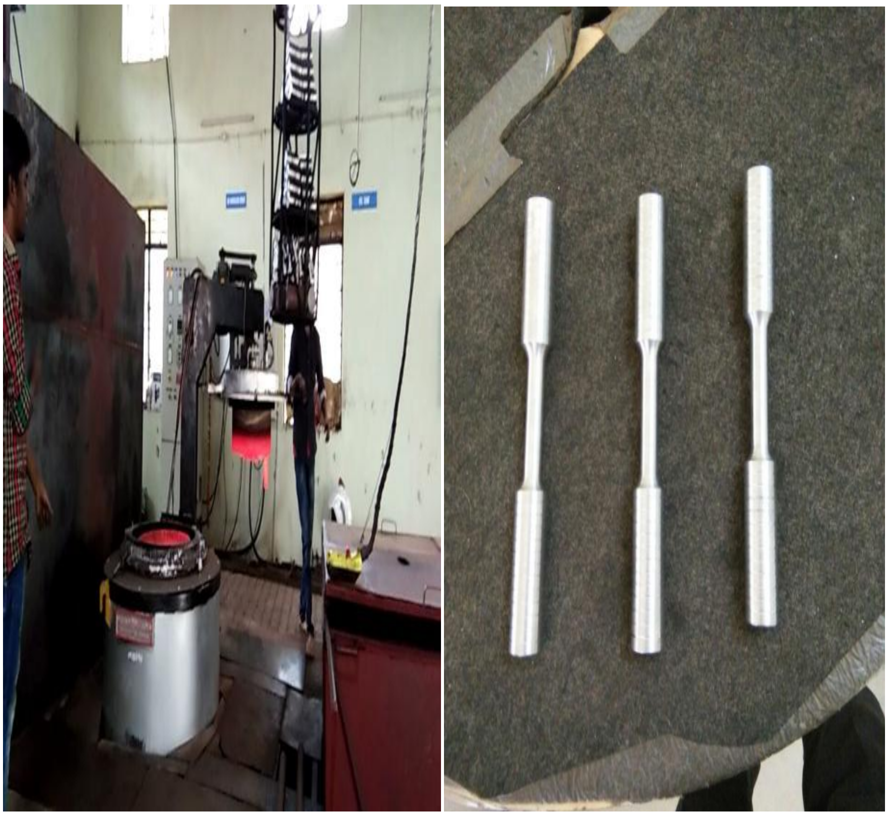

Fig. 1 shows the prepared samples, and experimentation.

IV. Results and discussion

A) Hardness

Fig. 2 shows the micro hardness values of untreated, hardened and hardened-tempered samples.

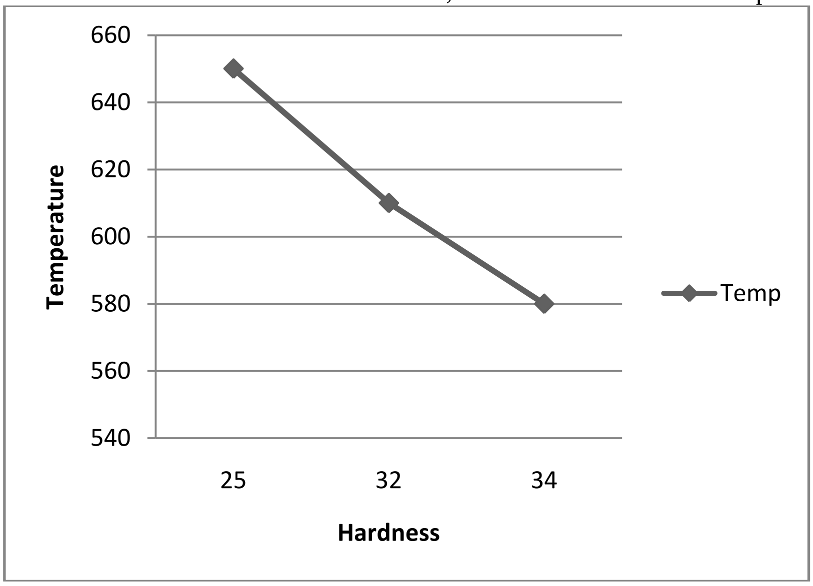

Fig.2: Variation of Hardness value of Tempered samples against three different temperatures

As tempering temperature increases, hardness gradually decreases. Sample hardened at 850°C give the highest hardness value (42HRC) compared to as received and tempered counterpart. The steel material with approximate 0.35 carbon when heated to 550°C and soaked for 1 hr, would have the carbon present dispersed to form austenite structures. The quenched specimens would have theiraustenites transformed to martensites. These are fine, needle-like structures which are very strong and hard, but very brittle. After the hardened steel tempered the prevalent martensite is an unstable structure and the carbon atoms diffuse from martensite to form a carbide precipitate and the concurrent formation of ferrite and cementite. This allows microstructure modifications caused reduced in hardness level while increasing the ductility. The re-heating of martensites during tempering would enable it to be transformed into sorbite or troostite. These are fine dispersions of carbide in a ferrite matrix.

B) Strength

Table 2 & 3 shows properties of specimen before and after treatment.

Table 2: properties of specimen before treatment.

	Before tempering		After tempering	
Temp. ^{0}C	**T.S. (N/mm^2)**	**Y.S. (N/mm^2)**	**T.S. (N/mm^2)**	**Y.S. (N/mm^2)**
580	616.73	463.61	1108	834
610			1045	804
650			1014	779

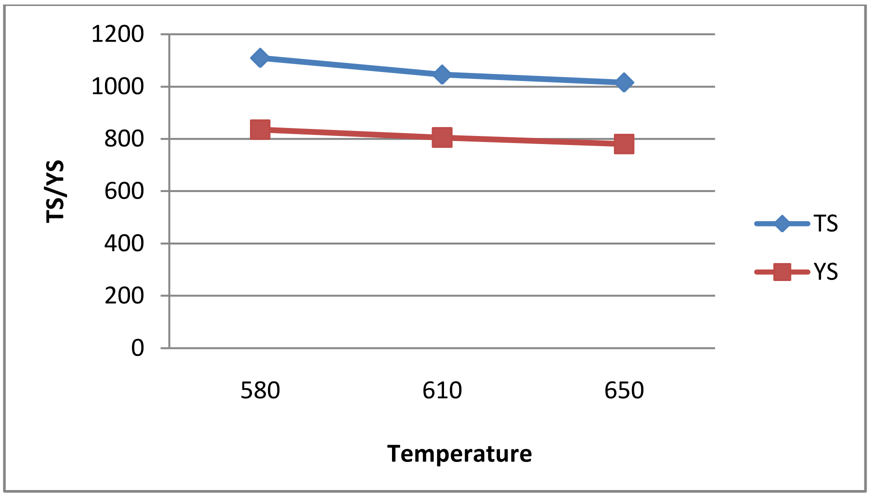

Fig.3: Variation of TS and YS of tempered samples against temperatures

Strength first increases to a maximum and then keeps on decreasing as temper temperature increases. The two curves are almost overlapping each other, indicating that there is only a marginal effect due to the difference in the heat treatment sequence. Maximum tensile strength of about 1108N/mm^2 occurs at tempering of 580°C for the oil-quenched hardened-tempered samples. It should be noted hat ultimate strength variation has almost the same pattern as hardness variation. This confirms that there is an almost direct relationship between hardness and strength, just as or most of the other steels. Similarly, the yield stress reached its maximum when hardened due to martensite formation as explained earlier and it then rapidly decreases after tempered from 580 to 650°C and continue to steadily decrease. investigation reveals that the hardened samples give the highest hardness and strength values while highest hardness and strength values for the tempered samples was obtained at temperature of 580°C.

C) Ductility

Table 3: properties of specimen (25 mm dia) after tempering at three different temperatures.

Temp. ^{0}C	**Hardness (HRC)**	**Elongation (%)**	**Reduction in A (%)**
580	34	13	55
610	32	11	36
650	25	17	55

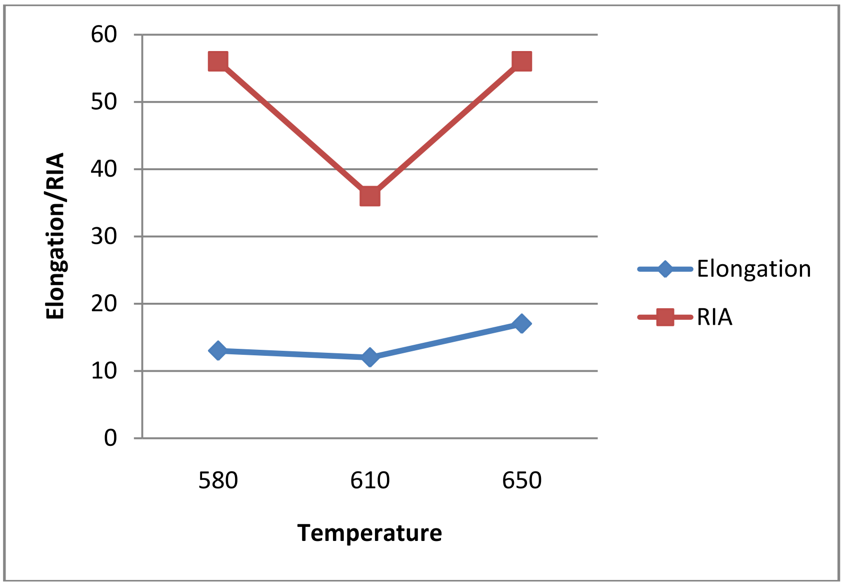

Fig.4: Variation of elongation and reduction in area of tempered samples against temperatures

The ductility of hardened sample was the least as compare to untreated sample (21.17%), but increases when tempered at 580°C(13.17%), with slight decrease at 610°C (11.67%) and and then increases sharply for 650°C(17.17%) tempered sample. This could be as a result of ferrite and cementite formed from the martensite. The highest value of ductility of about 17.17% was obtained on the sample with highest tempering temperature of 650°C. This is because tempering treatment at elevated temperature is able to increase the number of planes on treated sample for dislocation movement to occur.

D) Microstructural Investigation

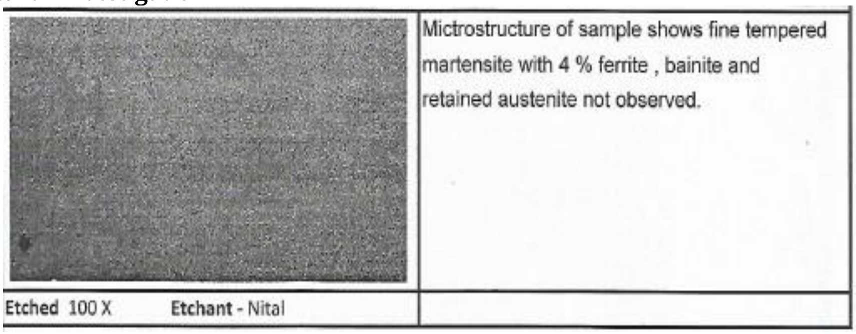

Fig. 5: Microstructure of EN-24 before treatment

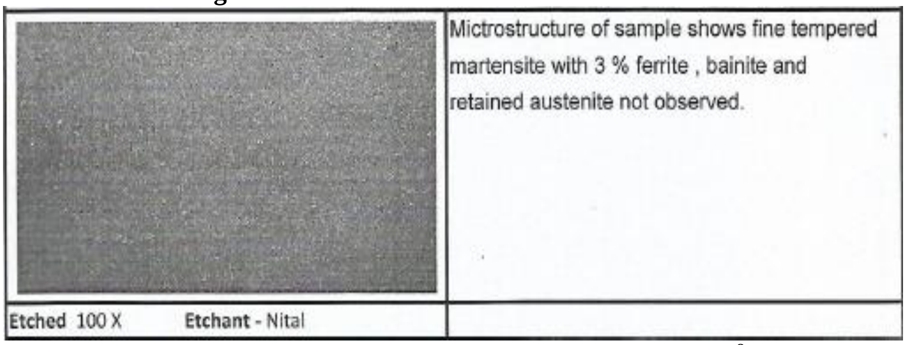

Fig. 6: Microstructure of EN-24 After tempering at 580 ^{o}C.

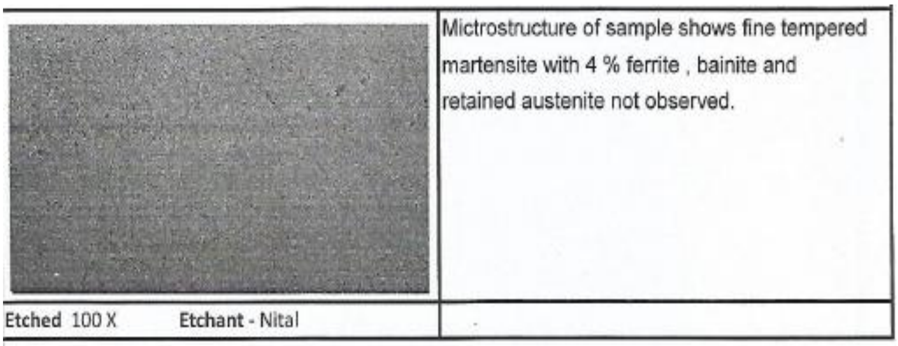

Fig. 7: Microstructure of EN-24 After tempering at 610 ^{o}C.

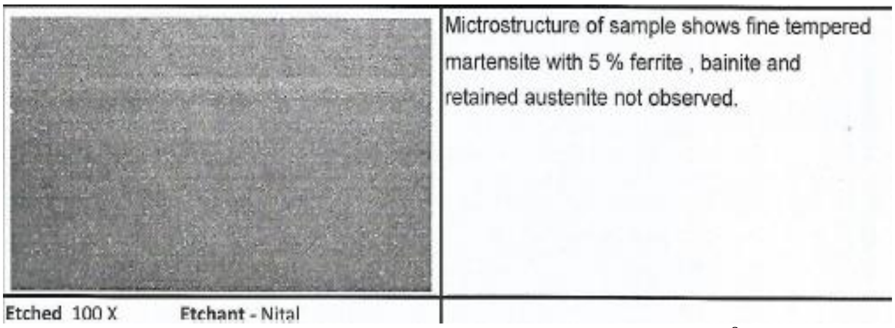

Fig. 8: Microstructure of EN-24 After tempering at 650 ^{o}C.

Specimens were first polished with belt polisher then followed by 1/0, 2/0, 3/0, 4/0 grades of emery paper & finally cloth polishing was done with alumina slurry followed by diamond polishing. Then etched with 2% nital. Metallographic images were taken with the help of computer integrated optical microscope at 100X magnification.

V. Conclusion

The influence of heat treatment process and temperature on mechanical properties of untreated, and hardened -tempered EN-24 steels was evaluated. The investigation reveals that the hardened samples give the highest hardness and strength values while highest hardness and strength values for the tempered samples was obtained at temperature of 580°C. So 580°C was found to be an optimum temperature for well balanced mechanical properties of EN -24 steel.

Acknowledgement

Project sponsored out of Mahalakshmi Metal Heat, UdyambagBelgavi. We thank Director and staff of this industry who provided insight and expertise that greatly assisted the project.

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