Determination of Tempering Temperature and It's Effect on Different Sized Specimen of EN 24 Steel

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ABSTRACT

The paper presents results of research by determining tempering temperature of desired hardness (ranges from 20-40 HRC) and effects of this tempering temperature on microstructure and mechanical properties of different sized EN-24 steel specimens. Tempering temperature is decided by hardness values got after quenching process. Tempering of the investigated steel was carried out at the temperatures of 580^{0}C, 610^{0}C, 650 ^{0}C. 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 of material, 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.

EN-24 steel is widely used in aircraft, particularly in critical applications such as landing gears, as a structural steel for aircraft and automobiles (military as well as commercial), aerospace equipments, shafts, crank shafts, connecting rods,heavy duty axel, etc.

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 and % 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. Chemical Composition (in weight %) of En-24 Steel Used.

C	Si	Mn	S	P	Ni	Mo	Cr	Cu	Ti	Al	Fe
0.35	0.27	0.55	0.03	0.03	1.43	0.19	0.92	0.09	0.001	0.01	96.02

III. METHODOLOGY OF RESEARCH

Three samples each of diameter 25, 40, 70, 90 mm (i.e. total 12 samples) were made up of En-24 steel on lathe machine. Samples were subjected to different heat treatment sequences: stress relieving, hardening, oil quenching, and tempering at three different temperatures: 580^{0}C, 610^{0}C, 650 ^{0}C. Heat treated specimens were mechanically tested for yield stress, ultimate tensile strength, % elongation and % reduction in area.

A) Heat Treatment

Prepared test samples were heated to relieve stress at 550°C, soaked for 1 hr using a pit type electric furnace and then cooled in air. The test samples then hardened by heating at 850°C, soaking for 90 min and quenched in oil (temperature below 80°C) for 20 min. After hardening the samples were divided into three sets. Each set consist 1 sample each of diameter 25, 40, 70 and 90mm respectively. Tempering treatment was conducted immediately on all three sets having 4 samples each at different temperatures of 580^{0}C, 610^{0}C, 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, hardened and hardened-tempered samples to evaluate their tensile and hardness properties. A Rockwell type C 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; during which 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 resultant 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

Table 2. shows the hardness values of specimens after tempering.

Tempering temperature(˚c)	Hardness (HRC)			
	25mm	40mm	70mm	90mm
580	34	38	28	28
610	32	36	31	25
650	25	32	27	24

Table. 2 shows the micro hardness values of hardened-tempered samples.

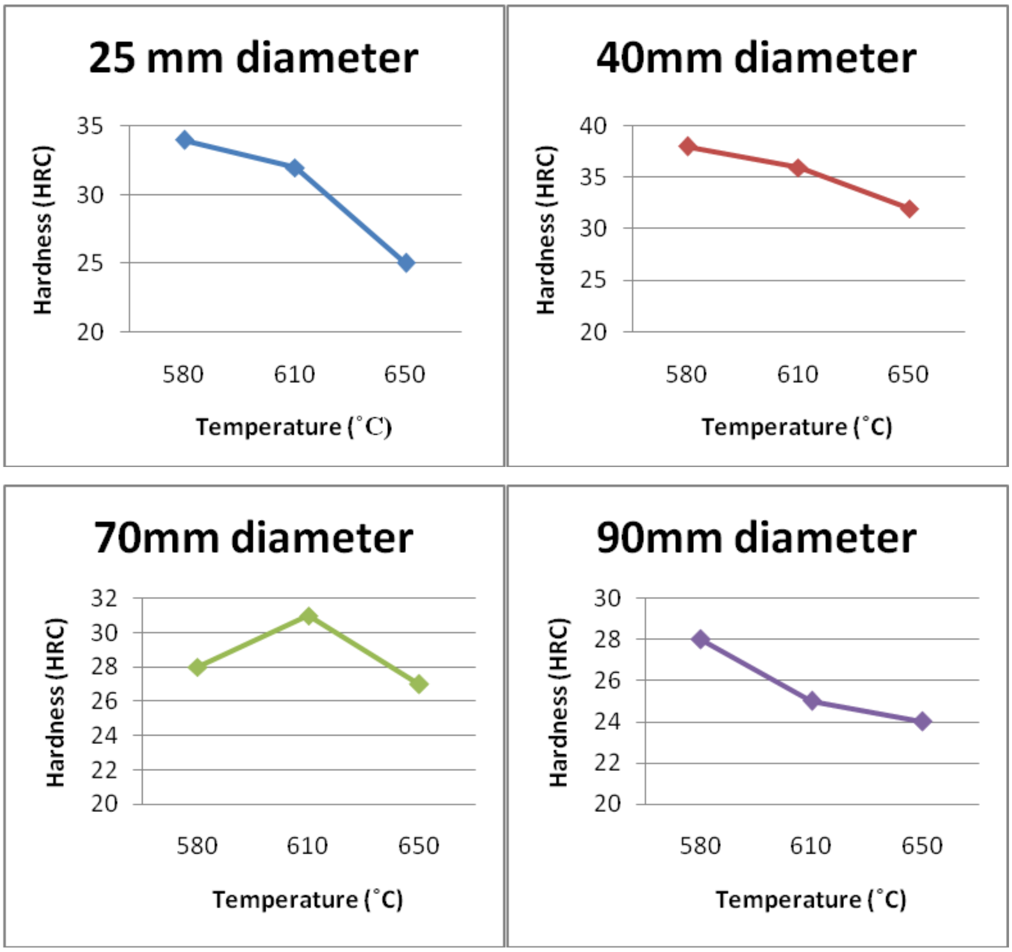


Fig.2: Variation of Hardness value of Tempered samples against three different temperatures for different diameters.

In case of 25mm, 40mm, 90mm, hardness gradually decreases as tempering temperature increases. And in case of sample of 70mm diameter, hardness gradually increases from 580°C to 610°C and then gradually decreases upto 650°C.Sample hardened at 850°C give the highest hardness value (42HRC) compared to asreceived 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 their austenite transformed to martensite. These are fine, needle-like structures which are very strong and hard, but very brittle.

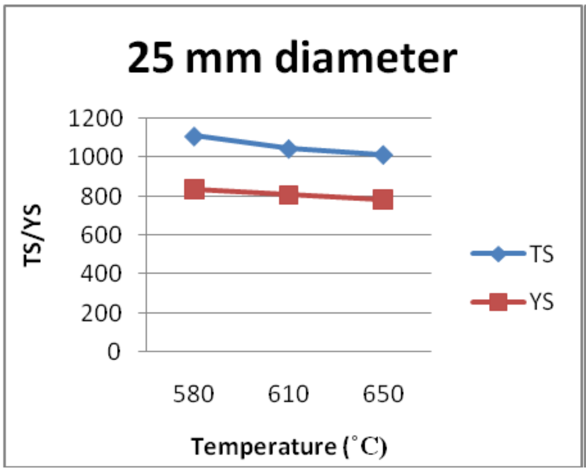
After the hardened steel tempered the prevalent martensite is an unstable structure and the carbon atoms diffuse from martensite to form a carbide precipitate and the concurrent formation of ferrite and cementite. This allows microstructure modifications caused in reduced hardness level while increasing 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.

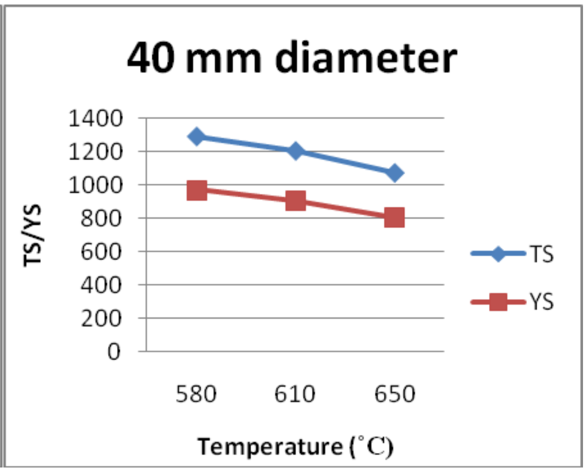
B) Strength

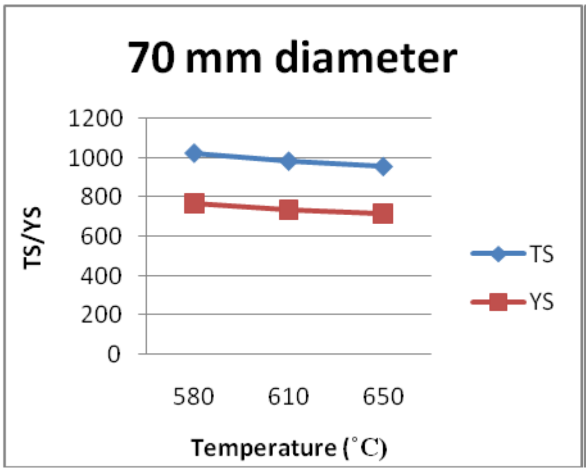
Table 3 shows strength of specimen before and after heat treatment.

Temp. ˚C	Before Heat Treatment		After Tempering							
			25 mm diameter		40 mm diameter		70 mm diameter		90 mm diameter	
	T.S. (N/mm²)	Y.S. (N/mm²)	T.S. (N/mm²)	Y.S. (N/mm²)	T.S. (N/mm²)	Y.S. (N/mm²)	T.S. (N/mm²)	Y.S. (N/mm²)	T.S. (N/mm²)	Y.S. (N/mm²)
580	616.73	463.61	1108.99	834.92	1291.82	971.07	1023.41	769.50	990.52	744.04
610			1045.34	804.61	1205.86	906.39	982.39	737.68	901.76	673.67
650			1014.92	779.76	1073.98	806.63	954.81	716.81	954.10	721.41

Table. 3: Properties of specimen before and after treatment.







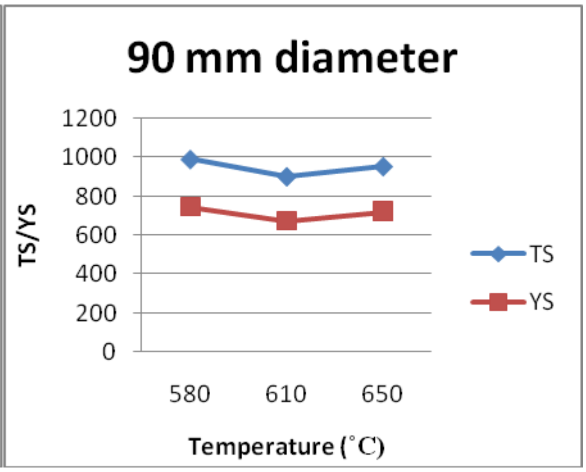


Fig.3: Variation of TS and YS of tempered samples against temperaturesfor different diameters.

In case of all the samples mentioned above, strength first increases to a maximum and then keeps on decreasing as tempering temperature increases. The two curves for respective sized specimens are almost overlapping each other, indicating that there is only a marginal effect due to the difference in the heat treatment sequence. It should be noted that 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 when tempered from 580°C to 650°C and continue to steadily decrease.

B) Ductility

Table 4: Ductility of specimens before and after tempering at three different temperatures.

Temp. ˚C	Before Heat Treatment		After Tempering							
			25 mm diameter		40 mm diameter		70 mm diameter		90 mm diameter	
	Elongation (%)	Reduction Area (%)	% E	% R. A.	% E	% R. A.	% E	% R. A.	% E	% R. A.
580	21.17	65.00	13.17	55.56	10.00	30.57	6.67	9.76	6.67	15.98
610			11.67	36.01	8.33	17.37	9.50	15.98	8.33	19.01
650			17.17	55.56	12.00	42.50	10.00	24.90	11.17	30.57

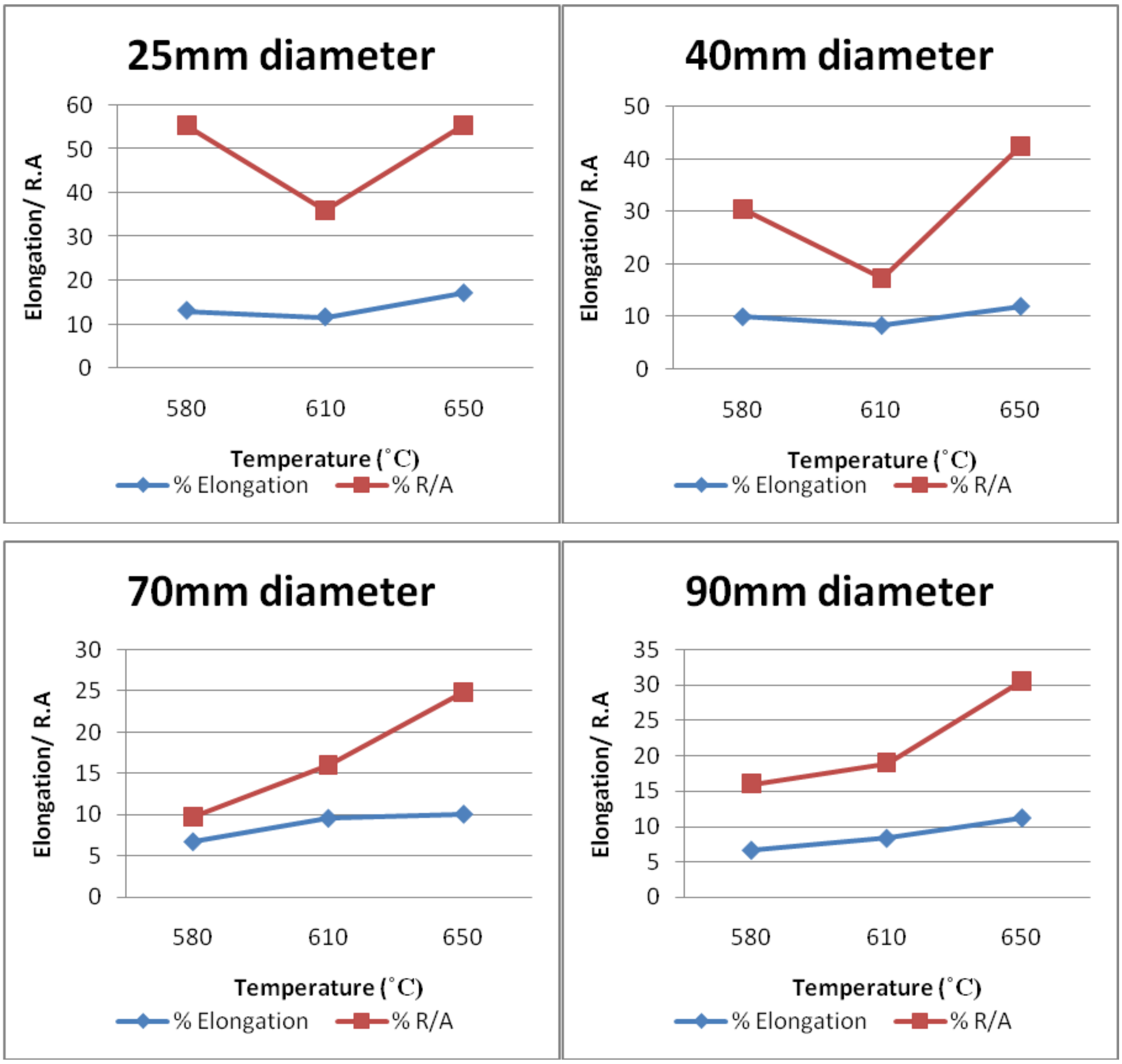


Fig.4: Variation of elongation and reduction in area of tempered samples against temperaturesfor different diameters.

The ductility of hardened sample was the least as compare to untreated sample, but in case of 25mm and 40mm, the ductility increases when tempered at 580°C, with slight decrease at 610°C and then increases sharply for 650°C tempered sample and in case of 70mm, 90mm, the ductility continuously increases from 580°C to 650°C. This could be as a result of ferrite and cementite formed from the martensite. This is because tempering treatment at elevated temperature is able to increase the number of planeson treated sample for movement to occur.

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D) Microstructural Investigation

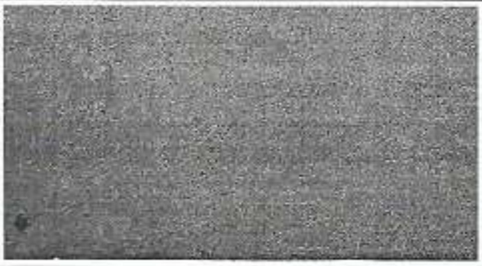	Mictrostructure of sample shows fine tempered martensite with 4 % ferrite , bainite and retained austenite not observed.
Etched 100 X Etchant - Nital	

Fig. 5: Microstructure of EN-24 before treatment

	Mictrostructure of sample shows fine tempered martensite with 3 % ferrite , bainite and retained austenite not observed.
Etched 100 X Etchant - Nital	

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

	Mictrostructure of sample shows fine tempered martensite with 4 % ferrite , bainite and retained austenite not observed.
Etched 100 X Etchant - Nital	

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

	Mictrostructure of sample shows fine tempered martensite with 5 % ferrite , bainite and retained austenite not observed.
Etched 100 X Etchant - Nital	

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. The etched with 2%nital. Metallographic images were taken with the help of computer integrated optical microscope at 100Xmagnification.

V. CONCLUSION

The influence of heat treatment process and temperature on mechanical properties of untreated, and hardened-temperedEN-24 steels was evaluated for the same steel grade EN-24, with different diameters applied to same heat treatment cycle. The results are as follows:

1. It is easier to get martensite in small diameter than big diameter specimens.
2. In case of small diameter, properties are uniform from center to surface.
3. Increase in section size, properties will non uniform from center to surface i.e. the Hardness and strength (Tensile Strength, Yield Strength) of material decreases and ductility increases.

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