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Study the Effects of Heat Treatment on Grade E Steel for Knuckle Coupler Application

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Abstract

Knuckle coupler failure accounts for about one lakh train separations a year, or about 275 separations per day. Problems in the manufacturing of Grade E steel knuckle coupler are differences in the chemical composition, improper heat treatment and casting defects. Among them improper heat treatment is the major problem so the present work deals with a systematic study on heat treatment of Grade 'E' coupler steel to understand the effect of heat treatment on microstructure and mechanical properties- hardness in particular. Six Grade E steel samples were cut into 25 x 25 x 25 mm3 of cube. These were subjected to heat treatment cycles which include austenitizing, quenching, tempering and air cooling for preselected time durations. Time duration for austenitizing and tempering used were 2, 2.5, 3, 3.5, 4 and 4.5 hrs. Quenching was done with in 30 sec. After tempering the samples were air cooled to bring them to room temperature.

Microstructure was obtained using optical microscope. XRD patterns were studied to find out phases present in the steel. Hardness was measured using Rockwell hardness machine. Results were used to study the effects of tempering time in the heat treatment cycle on the mechanical properties, and hardness in particular.

Keywords

Knuckle Coupler, Austenitizing, Quenching, Tempering

I. Introduction

A coupling (or a coupler) is a mechanism for connecting rolling stock in a train as shown in fig. 1 and fig. 2. The design of the coupler is standard, and is almost as important as the track gauge, since flexibility and convenience are maximized if all rolling stock can be coupled together.

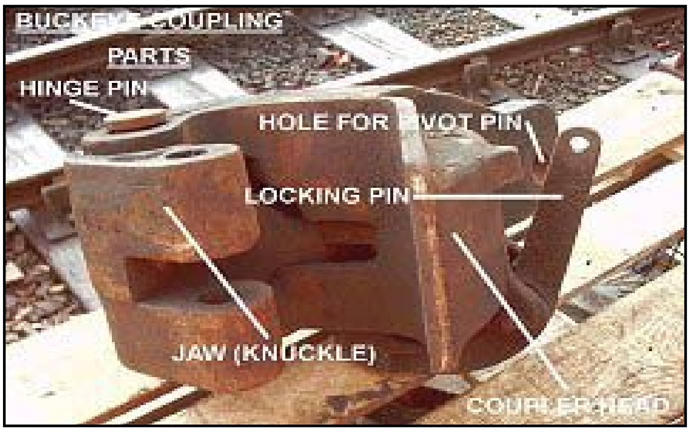

Fig. 1: Shows Knuckle Coupler

Fig. 2: Shows Knuckle Coupler Connecting Rolling Stocks in a Train

II. Manufacturing of Knuckle Coupler

A. Process of Steel Making

All steel melting and refinement is to be performed with the use of an Electric Arc Furnace. The ladle analysis of steel are carried out by spectrometer to determine the percentage of carbon, manganese, phosphorous, sulphur, silicon chromium, nickel & molybdenum as shown in Table 1.

Table 1: Shows Chemical Composition That are Required for Grade E

Elements	wt%
Carbon	0.28-0.33
Manganese	0.60-0.90
Phosphorus	0.030Max
Sulphur	0.030Max
Silicon	0.040-0.60
Chromium	0.50-0.80
Aluminium	0.020-0.050
Nickel	0.50-0.60
Molybdenum	0.15-0.25

To enhance the strength and wearing properties, chromium is added along with manganese. The minimum strength is achievable when requisite chromium along with manganese is present. However, presence of molybdenum is unavoidable to eliminate the chances of temper brittleness while cooling after tempering. Nickel is added to impart sub-zero impact strength. In this context, it is relevant to mention that carbon-manganese ratio is also contributory within the preview of specified chemical properties. The ratio of C and Mn should be closely monitored. Aluminium is added as deoxidant and as grain refiner. But, it is preferred to keep aluminium as low as possible since it drastically reduces the subzero impact strength.

B. Methoding

Casting solidification software required to be utilized to evaluate castings for potential defects and to qualify the casting for production [10].

Standardized running, gating and risering system including use of chills and chaplets required to be developed with the help of casting solidification software and only such system be employed for regular production of castings [10].

Casting solidity required to be verified with the aid of casting solidification software to achieve proper internal solidity standards. These standards are to be measured by means of porosity percentage values [10].

C. Moulding

Moulding required to be carried out by employing either of the following process given below:

High Pressure Moulding Line with Intensive Mixture for Green sand mould with Automatic Moisture Control and addition of Binder in fixed rates.

or

Articulated Mixer (continuous type) with fume extraction facility & Compaction Table for No-Bake System. Mould hardness shall be minimum 85 and the same required to be uniform at all the surfaces (within + 5% at all the surface including vertical) so as to get good dimensional accuracy in castings [10].

D. Core Making

All cores required to be produced by No-bake process for which continuous mixer with compaction table/ batch mixer is needed. [10].

E. Melting

A sufficient carbon boil is to be accomplished with a 20 point carbon reduction. Double slag process for proper removal of sulphur and phosphorus is to be followed. Argon purging is to be carried out to ensure freedom from harmful gases. Ladle pre-heating at 600 to 700°C is to be carried out. Temperature checking in Furnace and in Ladle by Immersion Pyrometer is required to be done before pouring in Mould [9].

F. Pouring

During pouring in mould, temperature checking by Laser Beam Type Optical Pyrometer is done. After pouring castings is allowed to cool to a temperature below 300°C, at a rate that will not be injurious to the castings. Moulding boxes are opened to extract the castings after they have cooled down sufficiently to room temperature [9].

F. Fettling

Risers, runners and ingates are removed from the castings. Use of knock-off risers is preferred for improving the surface condition of the castings. All castings are cleaned, dressed and shot blasted to ensure freedom from surface imperfections, loosely adherent sand, scale etc. [9].

G. Heat-treatment

All castings are required to be heat treated after fettling. Grade E steel castings is furnished normalised, quenched and tempered. Grade B steel castings is furnished normalized and tempered. State-of-the-art heat treatment furnaces are employed and required to be capable of maintaining an even heat distribution within +/- 10°C throughout [9].

1. Preparation of Samples

Samples with dimensions of (25x25x25) mm^3 were cut using Automatic Abrasive Cutting machine as shown in Fig.

Fig. 3: Automatic Abrasive Cutting Machine Used for Cutting of Samples

III. Experimental Details

A. Heat Treatment

Heat treatment involved four stages as explained below:

1. Austenitisation:

The samples were heated in programmable type electrically heated SiC furnace as shown in fig. 3.3. Austenisation was carried out at temperature $T\gamma$ =920 °C for preselected time periods as shown in heat treatment cycles Fig 3.2). The time of austenitisation, $t\gamma$ used were 2 hrs, 2.5 hrs, 3 hrs, 3.5 hrs, 4 hrs, and 4.5 hrs.

2. Quenching:

Quenching was done by immediately (i.e. with in 30 sec) transferring the austenitised samples in water bath.

3. Tempering:

The samples were reheated in programmable type electrically heated SiC furnace at temperature Tt =625 °C for preselected time as shown in heat treatment cycles Fig 3.2. The time of tempering, tt varies as 2 hrs, 2.5 hrs, 3 hrs, 3.5 hrs, 4 hrs, and 4.5 hrs.

4. Air Cooling:

After tempering the samples were cooled in air to bring them to room temperature.

All the six samples were subjected to different heat treatment cycles as shown in fig.

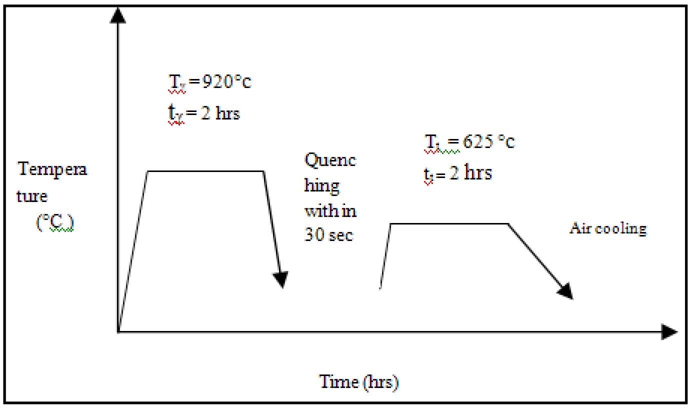

Fig. 3(a):

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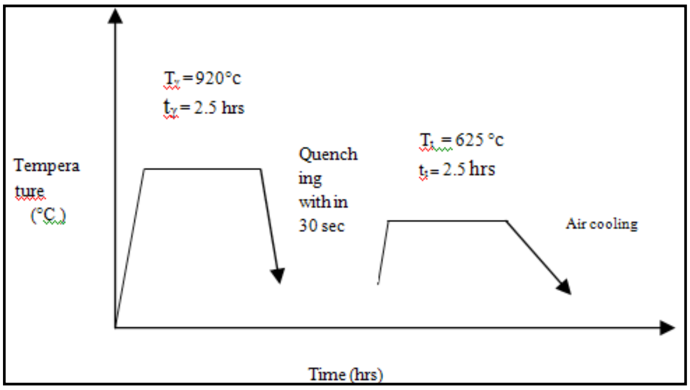

Fig. 3(b):

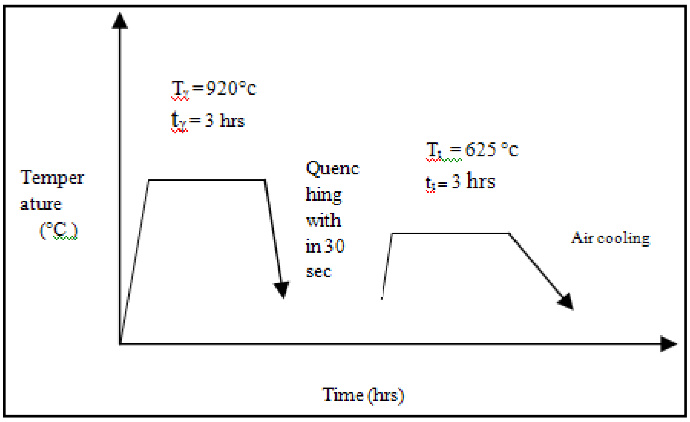

Fig. 3(c):

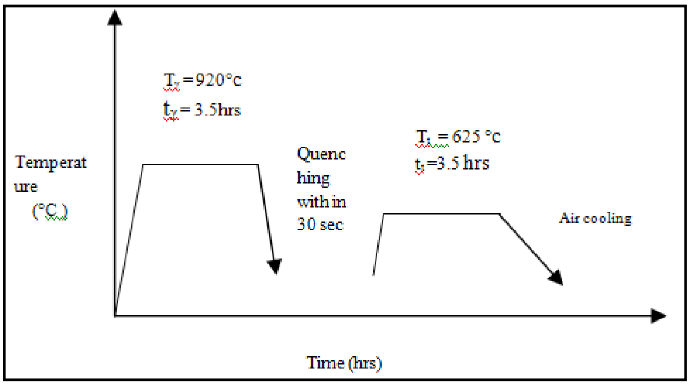

Fig. 3(d)

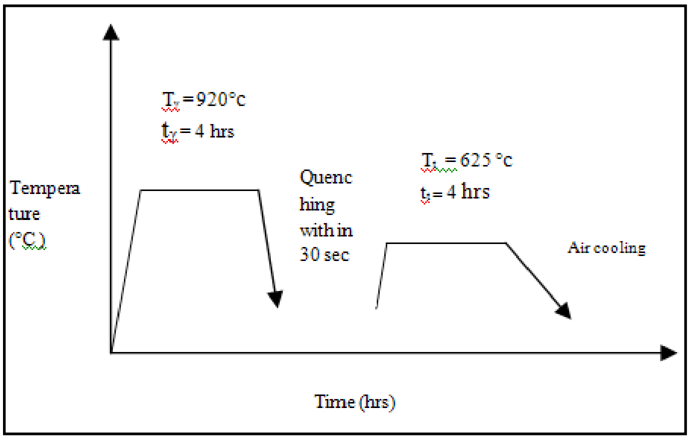

Fig. 3(e)

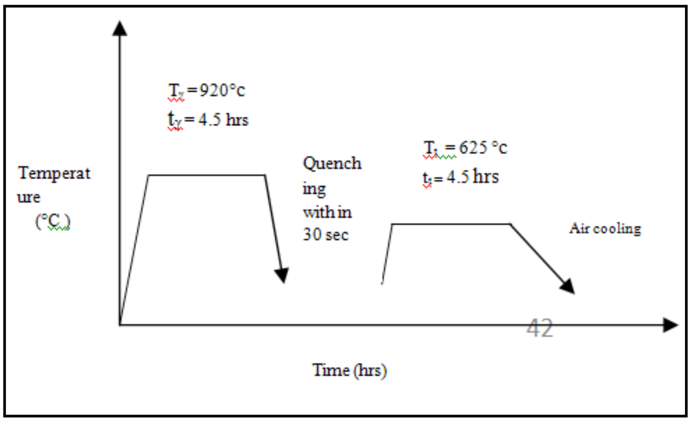

Fig. 3(f)

IV. Results

A. Micro Structural Study

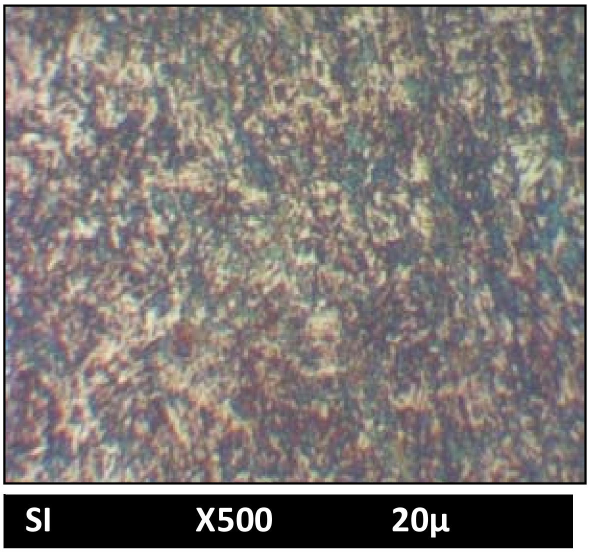

Fig. 4: Microstructure of Grade E Steel Subjected to Heat Treatment Profile 3 (a) i.e.(Tγ = 920°C, tγ = 2 hrs , Tt = 625°C, tt = 2 hrs) at 500x

The microstructure consists of fine tempered martensite.

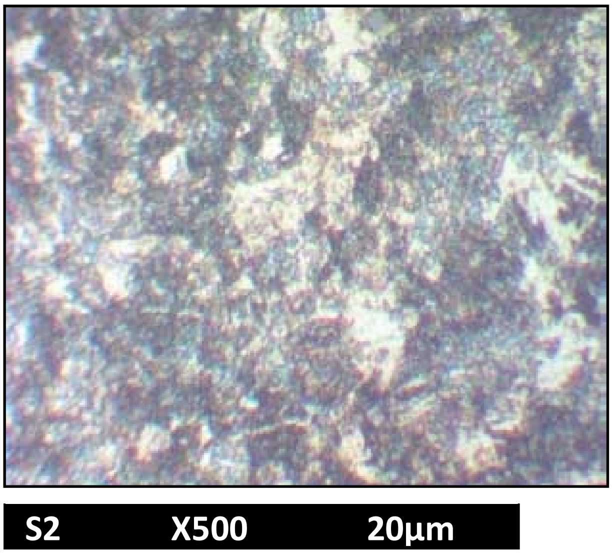

Fig. 5: Microstructure of Grade E Steel Subjected to Heat Treatment profile 3 (b) i.e.(Tγ = 920°C, tγ = 2.5 hrs , Tt = 625°C, tt = 2.5 hrs) at 500x

The microstructure consists of fine tempered martensite.

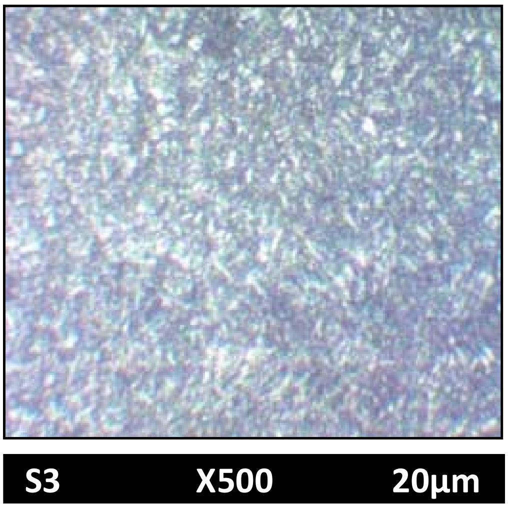

Fig. 5: Microstructure of grade E steel subjected to Heat Treatment profile 3(c) i.e.(Tγ = 920°C, tγ = 3 hrs , Tt = 625°C, tt = 3 hrs) at 500x

The microstructure consists of fine tempered martensite.

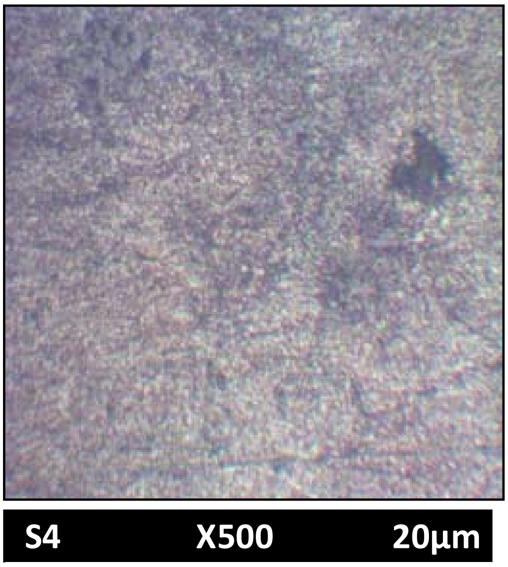

Fig. 6: Microstructure of grade E steel subjected to Heat Treatment profile 3(d) i.e.(Tγ = 920°C, tγ = 3.5 hrs , Tt = 625°C, tt = 3 hrs) at 500x

The microstructure consists of fine tempered martensite.

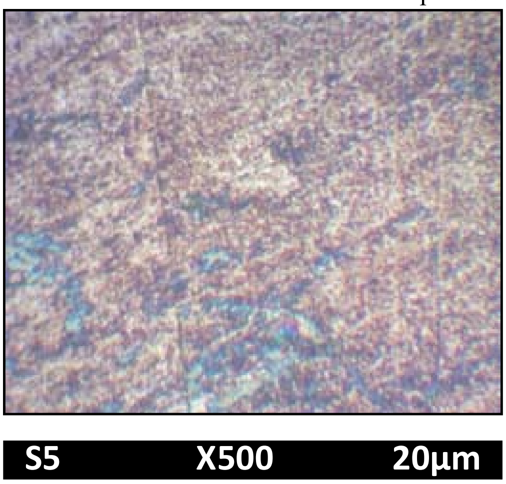

Fig. 7: Microstructure of grade E steel subjected to Heat Treatment profile 3(c) i.e.(Tγ = 920°C, tγ = 4 hrs , Tt = 625°C, tt = 5 hrs) at 500x

The microstructure consists of fine tempered martensite

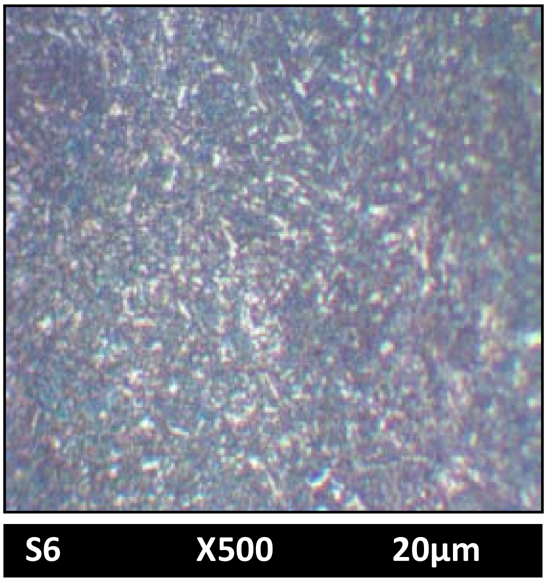

Fig. 8: Microstructure of grade E steel subjected to Heat Treatment profile 3(e) i.e.(Tγ = 920°C, tγ = 4.5 hrs , Tt = 625°C, tt = 4.5 hrs) at 500x

The microstructure consists of fine tempered martensite

B. XRD Results

The highest peaks generated were of α-Fe(110), α'-Fe(211), γ -Fe (311) and γ-Fe (111) as shown in XRD graph plotted below in Fig 9.

ϒ-Fe(111)

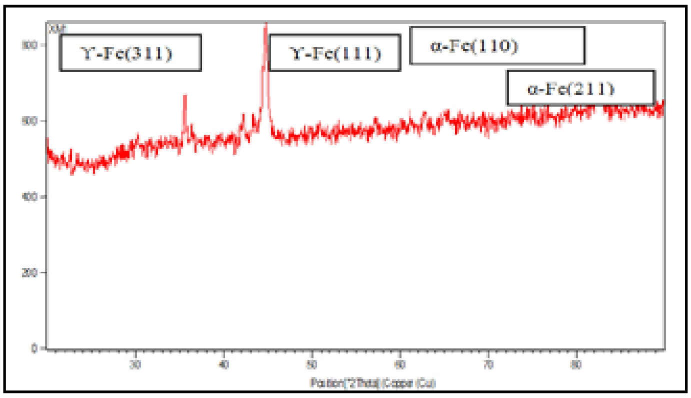

Fig. 9: XRD pattern of sample powder subjected to heat treatment cycle 3 (a)

Pos. [°2Th.]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Area [cts*°2Th.]
20.4421	0.8029	4.34462	4.95	11.68
30.2352	0.4015	2.95603	12.63	14.91
35.5872	0.1171	2.52279	44.48	15.31
42.2331	0.4684	2.13991	20.57	28.32
44.7793	0.1673	2.02397	100.00	49.17
62.7163	0.4015	1.48147	13.71	16.18
65.1553	0.8029	1.43179	8.29	19.56
82.4584	0.8160	1.16876	15.26	49.49

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The highest peaks generated were of α-Fe(110), α'-Fe(200), and γ -Fe (311) as shown in XRD graph plotted below in Fig 10.

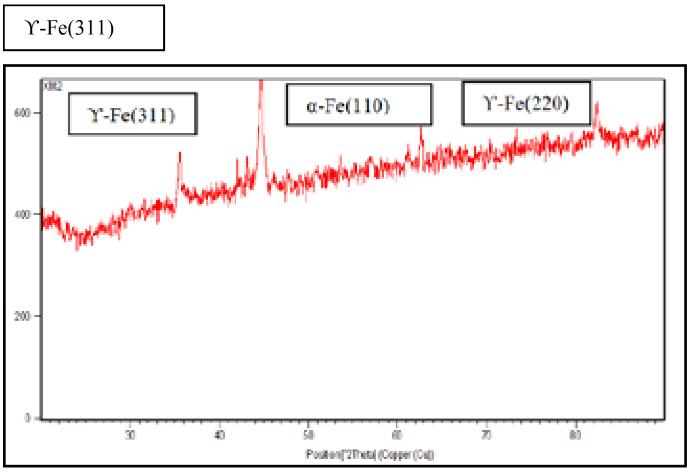

Fig. 10: XRD Pattern of Sample Powder Subjected to Heat Treatment Cycle 3 (b)

Pos. [°2Th.]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Area [cts*°2Th.]
35.5191	0.2007	2.52747	52.62	21.14
43.1633	0.2007	2.09592	25.48	10.24
44.7772	0.1673	2.02406	100.00	33.47
56.9440	0.8029	1.61714	12.51	20.09
62.6223	0.4015	1.48347	30.61	24.59
82.4063	0.4080	1.16937	27.80	30.68
35.5191	0.2007	2.52747	52.62	21.14
43.1633	0.2007	2.09592	25.48	10.24

The highest peaks generated were of α-Fe(110), α'-Fe(211), γ -Fe (111), and γ -Fe (311) as shown in XRD graph plotted below in Fig 11.

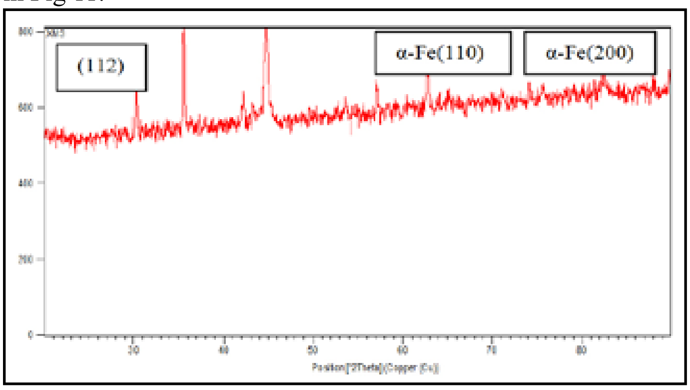

Fig. 11: XRD Pattern of Sample Powder Subjected to Heat Treatment Cycle 3 (c)

Pos. [°2Th.]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Area [cts*°2Th.]
30.2911	0.1338	2.95070	48.09	16.43
35.5676	0.1004	2.52414	100.00	25.63
42.2840	0.2676	2.13745	22.35	15.27
44.8021	0.3346	2.02299	91.54	78.20
53.6259	0.4015	1.70910	12.80	13.12
57.1368	0.2676	1.61214	30.25	20.68
62.7682	0.2007	1.48037	45.34	23.24
74.1090	0.2007	1.27941	18.12	9.29

The highest peaks generated were of α-Fe(110), α'-Fe(211), and γ -Fe (311) as shown in XRD graph plotted below in Fig 12.

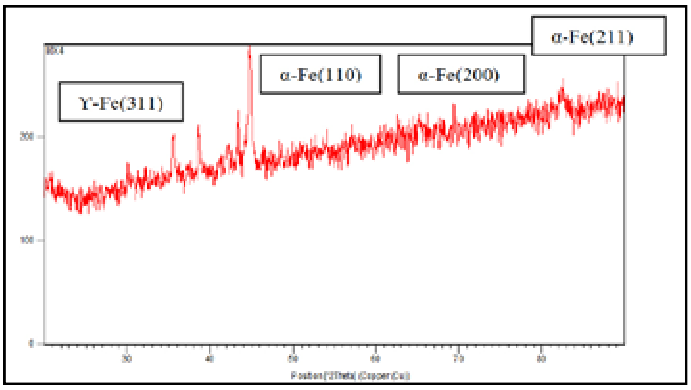

Fig. 12: XRD pattern of sample powder subjected to heat treatment cycle 3 (d)

Pos. [°2Th.]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Area [cts*°2Th.]
35.5927	0.4015	2.52241	38.27	15.83
38.6032	0.2007	2.33235	40.50	8.37
44.7700	0.4080	2.02269	100.00	56.81
82.5845	0.2682	1.16826	90.25	25.28

V. Hardness Test

The hardness measurements were plotted on bar chart with min. hardness and max. Hardness as shown below in fig. 13.

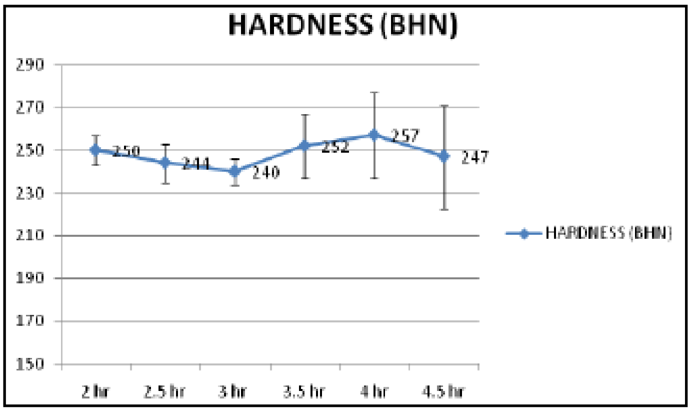

Fig. 13: Shows Hardness (BHN) for Heat Treated

VI. Conclusion

1. Grade E steel used from knuckle coupler, when heat treated using austenitisation temperature, Tγ = 920°C and tempering temperature, Tt = 625°C provides fine tempered martensite in its microstructure for tt = 2, 2.5, 3, 3.5, 4 and 4.5 hrs.
2. XRD shows presence of α, α' and γ in the XRD patterns. However the intensities of these peaks are varying. As the tempering time tt increases from 2 to 4.5 hrs the amount of γ decreases and α increases.
3. The hardness obtained for tt = 3.5 hrs or more lies in the range 241 to 291 BHN, as specified by Research Designs and Standards Organization (Indian railways).
4. The uniformity of microstructure seems to be the main issue. Since Grade E steel is an alloy steel containing Mo, Ni and Cr. The tempering requires larger tempering time at 625°C

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