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Effect on microstructure of TMT welded bar under different cooling media

Arc welding is widely used for domestic as well as industrial purposes as it is very convenient to use. Mechanical properties such as tensile strength and hardness depend on microstructure. This paper presents the results of metallography examination of weld zone and heat affected zone (HAZ) in the welded rod which are welded and cooled in air, transformer oil, kerosene oil and water. The rate of cooling differs from each media thus there is microstructure change in weld zone as well as HAZ. In the weld zone, hardness is found to be more in case of transformer oil cooled sample in comparison with others cooling method applied here. The toughness of water cooled sample is found to, be more because of its presence of large amount of ferrite region along with pearlite and martensite. In the heat affected zone, water cooled sample is found to possess mare hardness due to formation of martensite. The arc welded transformer oil cooled sample seems to be best among all with regard to its structure, hardness and toughness.

Keywords: TMT, microstructure, welding, quenching, heat affected zone.

1. Introduction

Thermo mechanically treated (TMT) bars are commonly used in making buildings. It is low carbon treated steel which poses very good mechanical properties compared to other low carbon steel. TMT bars are being made by heating steel between 1000ºC to 1200ºC and then quenched into quench box where the upper layer of the bar converted into hard martensite. Arc welding is one of the oldest welding method are being often used in industry and for domestic use. During arc welding small fraction of metal is melted by the heat produced by arc. Due to differential heating the material away from the weld bead is heated and as the weld bead approaches, higher temperature gradients are obtained which results in complex structure. Three distinct regions are produced due to temperature gradient know as weld metal zone, heat affected zone (HAZ) and base metal. All the three zones have different microstructure, which is the key governing factor for the material properties like hardness, toughness, strength etc. Cu -TMT bar weld metal has ferrite-pearlite structure and HAZ has widmanstatten (WD) ferrite structure with some bainite [2]. Similar result was obtained in industrial low carbon steel having 0.19 wt. % C as HAZ containing widmanstatten ferrite and some colonies of ferrite while base metal has equiaxed ferrite grains [3]. Apart from phase change there is change in grain structure also. Quenching is rapid cooling of steel from austenitizing temperature using suitable media [4]. No change has been noticed in the post weld treated by aging joints [5]. Optical microscopy of a failed concentric reducer tube samples revealed banded ferrite-pearlite structure. No structural abnormalities were found in the weld beads and heat-affected zones [6].

The experiments on arc weld TMT bar were carried out under different cooling medium. The samples have been divided into three distinct zones i.e. weld zone, heat affected zone and parent metal. The heat affected zone from the metallographic point of view has been further subdivided into three distinct zone i.e. (i) HAZ 1 which is adjacent to weld zone (7mm), (ii) HAZ 2 which is 15mm away from the weld zone and (iii) HAZ 3 which is near to the parent metal (Fig.1). After welding or joining the two rods, cooling has been carried in air, transformer oil, kerosene oil and water. The microstructure and hardness of the sample were of the above three zones under different cooling media have been evaluated. It has been observed that, as we move towards the parent zone grain size has been decreased. Also it has been observed that high heating in the welding zone resulted in coarser grain. Fast cooling resulted in smaller grains as in water cooling while slow cooling in transformer oil cooled specimen has resulted in coarser grain. Grain size has affected the mechanical properties like hardness and toughness. Hardness has increased for finer grains and the same is true for the toughness also. For the weld zone the transformer oil cooled sample shows the highest toughness amongst others.

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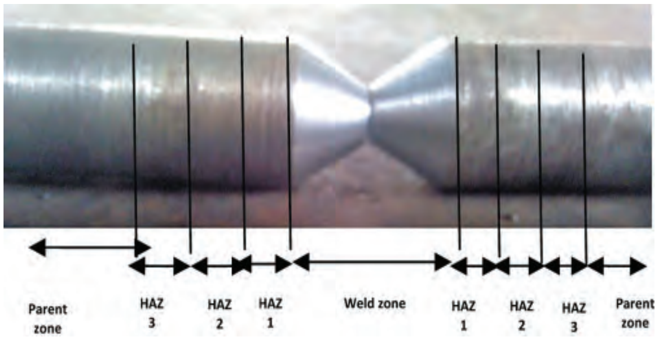

Fig.1 Specimens before welding

2. Experimentation

Arc welding was performed on TMT rod of length 100 mm and diameter 18mm. it was cut from the centre and a groove of 350 was made as shown in Fig 1. The rod was welded by arc welding and then machined to make a perfect round shape. After welding the specimens are cooled in four different types of cooling media, one specimen is left to cool in ambient air, one in water, one in transformer oil and one in kerosene oil. All the cooling media are kept at room temperature. Then the specimen has been machined in shaper to make flat surface and then grinded and polished using diamond paste to get perfectly polished surface. The samples of weld zone and heat affected zones are etched with 4% nital solution and its micro examination is carried out with optical microscope. The chemical analysis of weld zone and parent zone (TMT bar) is done using optical emission spectrometer and found that due to filler material composition the weld zone has lower carbon. The result of chemical test is shown in Table 1. The hardness of the samples are carried out in Brinell Hardness Testing Machine with Load = 750 Kg and Ball Dia = 5 mm (steel ball). Further the samples are cut into pieces of 100 × 10mm thickness and V-notch has been made to perform the Izod Impact test.

TABLE 1: CHEMICAL COMPOSITION OF PARENT AND WELD ZONE

Zone	C	Mn	Cr	Si	Ni
Parent	0.210	0.740	0.030	0.259	0.014
Weld zone	0.087	0.428	0.016	0.266	0.006

3. Result and discussion

3.1 MICROSTRUCTURE OF PARENT MATERIAL (TMT BAR)

The parent specimen contains bainite 80% and ferrite 20%. Its structure is different from other low carbon steel having same percentage of carbon due to deformation of austenite during hot rolling process. It contains dendrite grains which have a good strength and is being used for construction purpose (Fig.2).

The micro examination of weld zone and heat affected zones (HAZ) of arc welded and cooled TMT bar under different cooling medium have been discussed below.

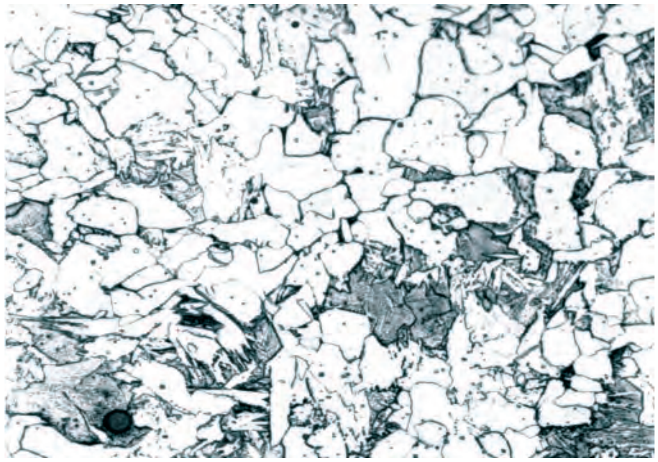

Fig.2: Parent (50X)

3.2 MICROSTRUCTURE OF WELD ZONE

The phase analysis of air cooled specimen shows that the weld zone contains 25% pearlite and 75% ferrite (Figs.3 and 4). The formation of columnar ferrite and carbides has also

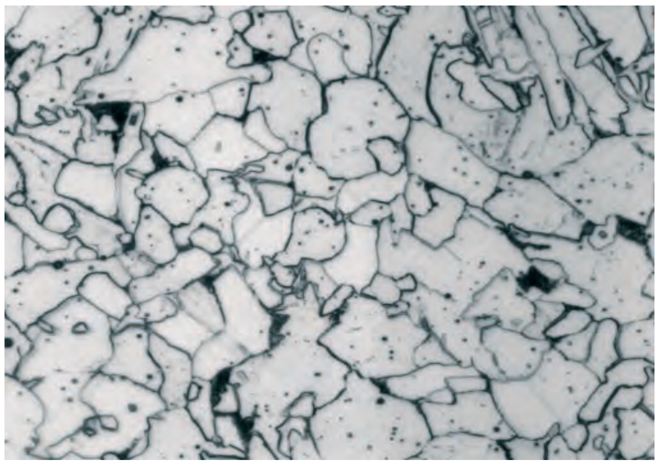

Fig.3 Weld zone of air cooled (50X)

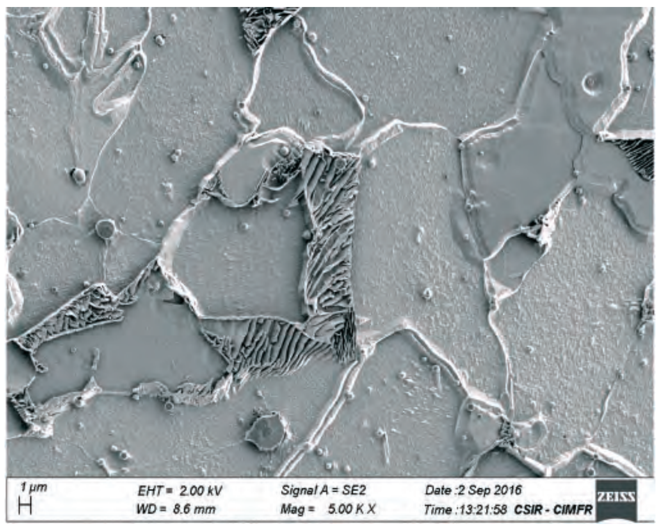

Fig.4 Weld zone of air cooled (5KX)

been observed. The transformer oil cooled specimen contains 52% ferrite and rest bainite and pearlite with formation of lamellar and dendritic structure. It contains columnar and dendritic ferrite along with carbides and upper bainite and pearlite (Figs.5 and 6). The kerosene oil cooled sample has 36% pearlite and 64% ferrite (Figs.7 and 8). Further the water cooled specimen has 26% martensite and 74% ferrite (Fig.9). Due to very fast heat extraction from the weld surface, there is formation of martensite which is confirmed by SEM images (Fig.10).

It can be observed from the above figures (3-10) that the microstructure varies under different cooling medium with regard to its grain size and phases. Air cooled specimen has coarser grain of ferrite along with less percentage of pearlite. Its hardness value is 170BHN and toughness is109.87 joule. The transformer oil cooled specimen has less ferrite region and formed phases of bainite and pearlite which is harder than only pearlite. This reflects on its hardness value which is 239 BHN and toughness is 112.82 joule. In case of kerosene oil cooled specimen, it has been observed that the ferrite percentage is greater than transformer oil cooled specimen but less than air cooled specimen. Its grains size is also

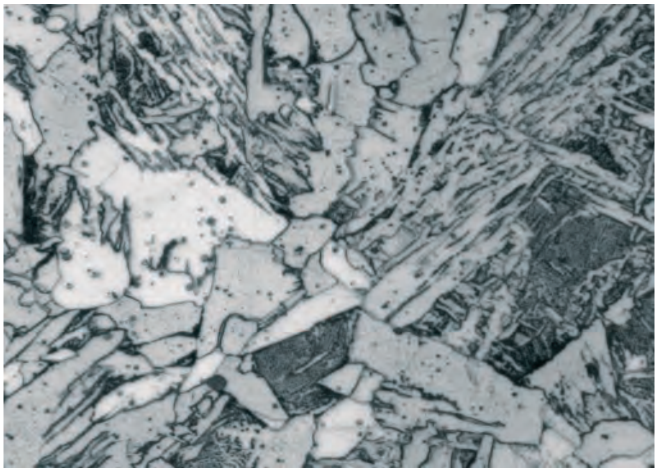

Fig.5 Weld zone of transformer oil cooled (50X)

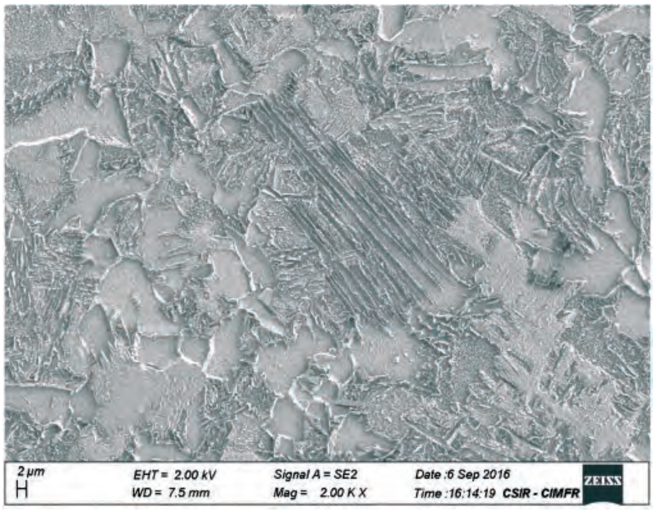

Fig.6 Weld zone of transformer oil cooled (2KX)

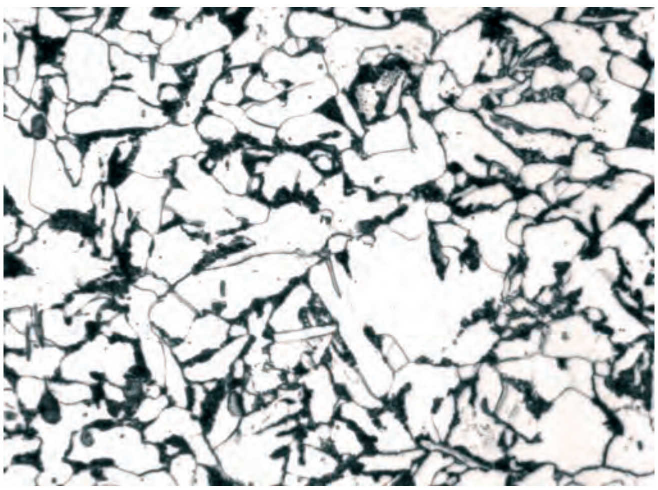

Fig.7 Weld zone of kerosene oil cooled (50X)

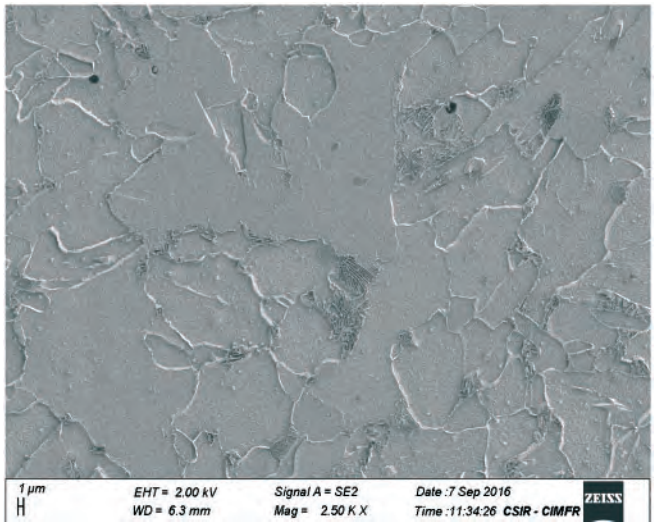

Fig.8 Weld zone of kerosene oil cooled (2.5 KX)

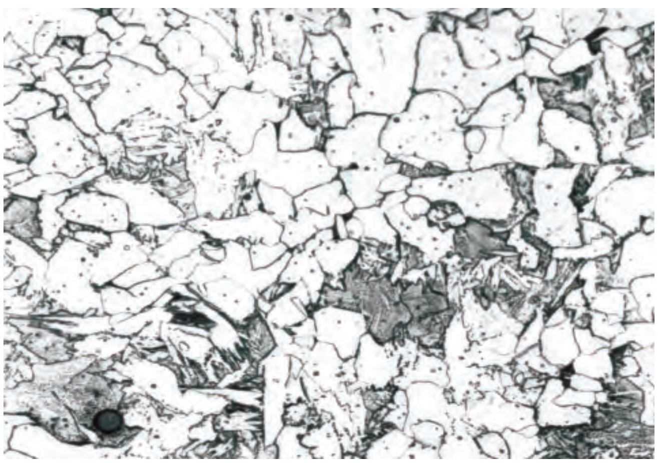

Fig.9 Weld zone of water cooled (50X)

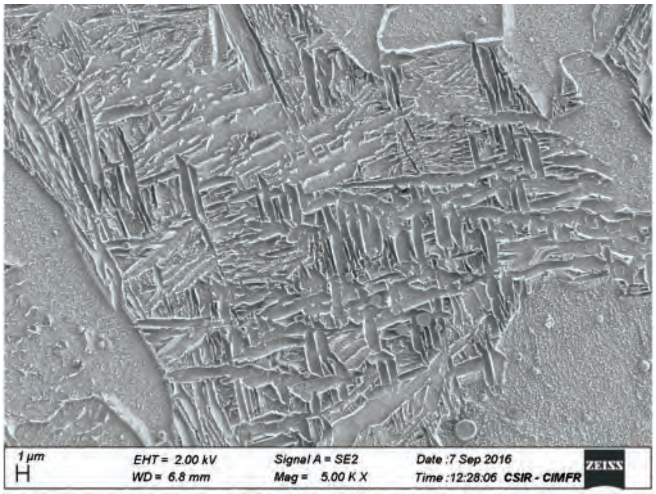

Fig.10 Weld zone of water cooled (5KX)

TABLE 2: BRIEF SUMMARY OF STRUCTURE, HARDNESS AND TOUGHNESS OF WELD ZONE

Cooling medium used	Microstructure	Hardness in BHN	Toughness in joule
Air	Ferrite - 75%	170	109.87
	Pearlite - 25%		
Transformer oil	Ferrite - 52%	239	112.82
	Pearlite+ bainite - 48%		
Kerosene oil	Ferrite - 64%	187	109.87
	Pearlite - 36%		
Water	Ferrite -74%	207	121.64
	Pearlite+ martensite - 26%		

coarse. This reflects in its hardness too. Its hardness is 187 BHN while toughness is found to be same as of air cooled specimen i.e. 109.87 joule. In water cooled specimen hard martensite has been formed so inspite of having high

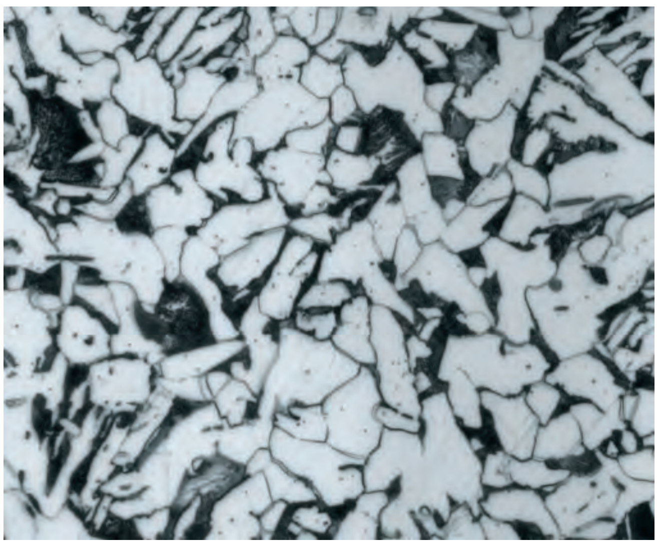

Fig.11 HAZ 1 of air cooled (50X)

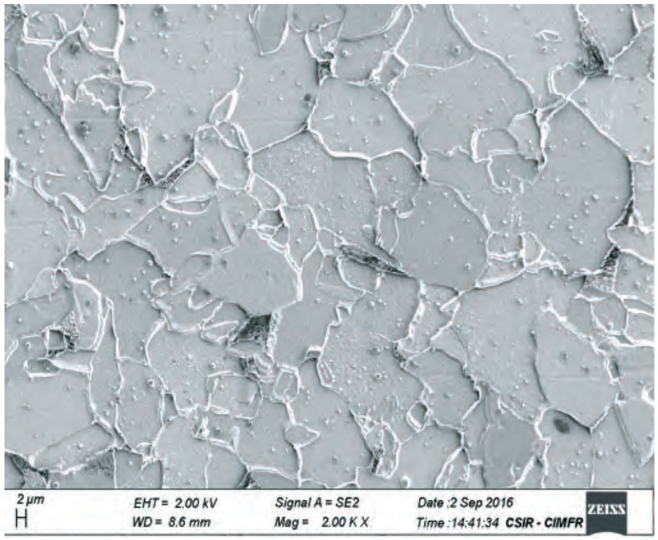

Fig.12 HAZ 1 of air cooled (2KX)

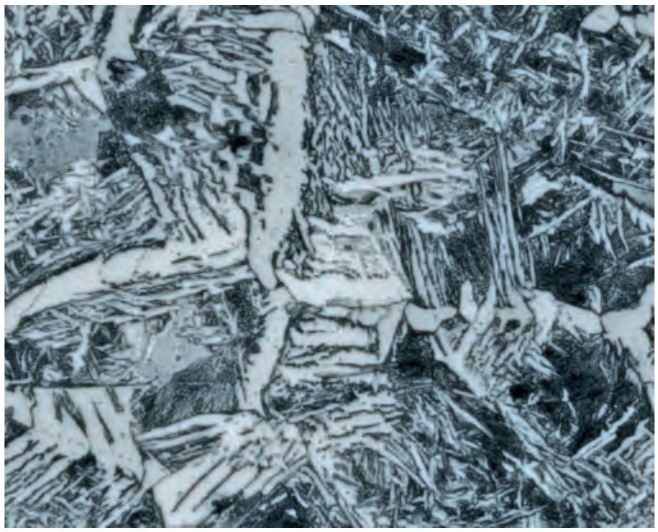

Fig.13 HAZ 1 of transformer oil cooled (50X)

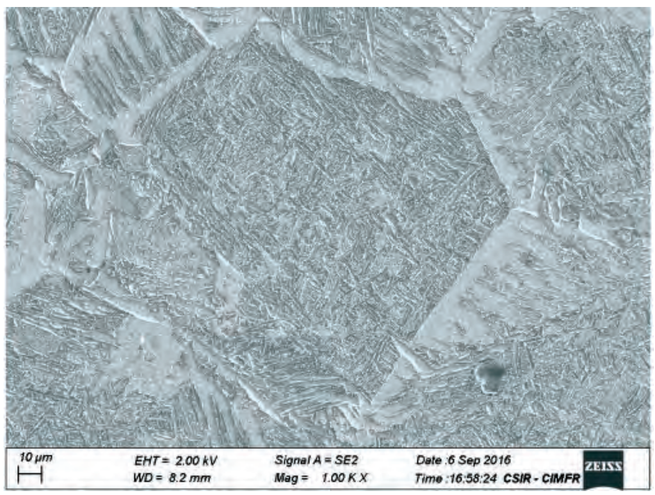

Fig.14 HAZ 1 of transformer oil cooled (1KX)

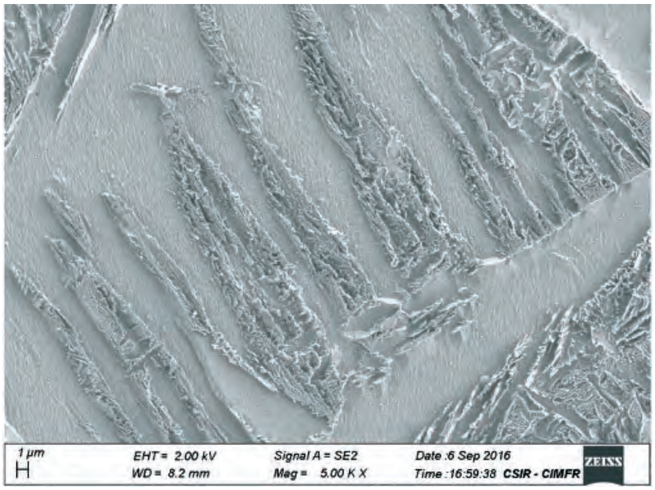

Fig.15 WD ferrite in HAZ 1 of transformer oil cooled

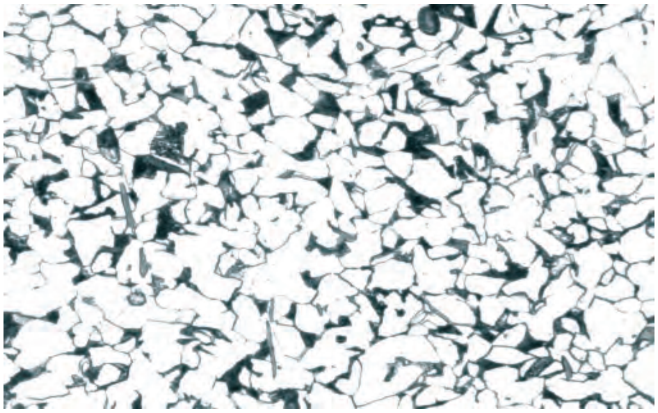

Fig.16 HAZ 1 of kerosene oil cooled (50X)

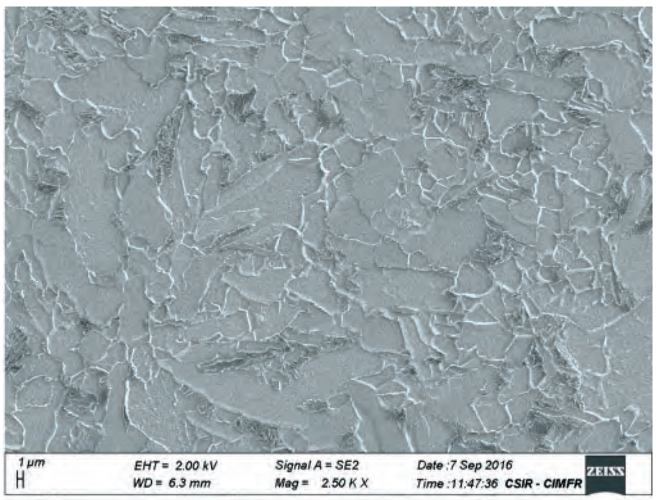

Fig.17 HAZ 1 of kerosene oil cooled (2.5X)

percentage of ferrite grain, its hardness has been increased to 207 BHN and its toughness also is found to be high as 121.64 joule due to its significant presence of martensite along with pearlite. From above it can be said that weld zone sample cooled in transformer oil have the good microstructure with

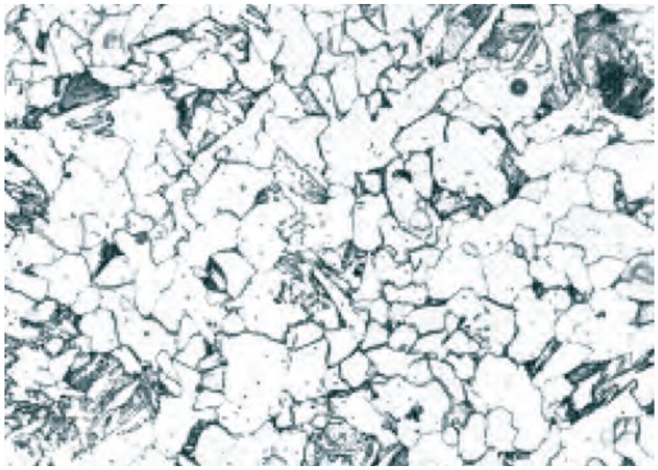

Fig.18 HAZ 1 of water cooled (50X)

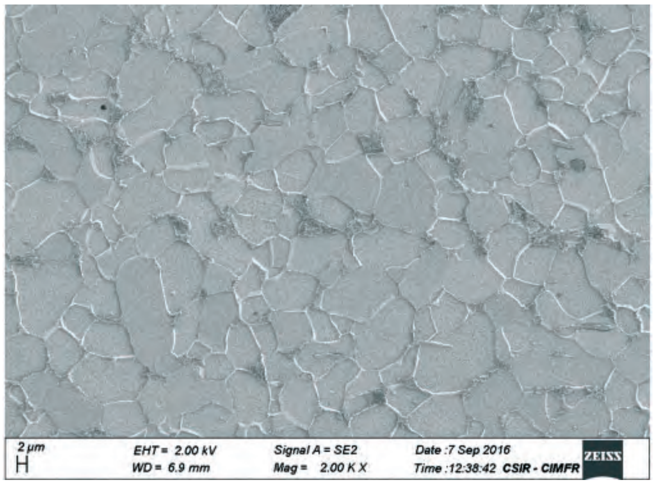

Fig.19 HAZ 1 of water cooled (2KX)

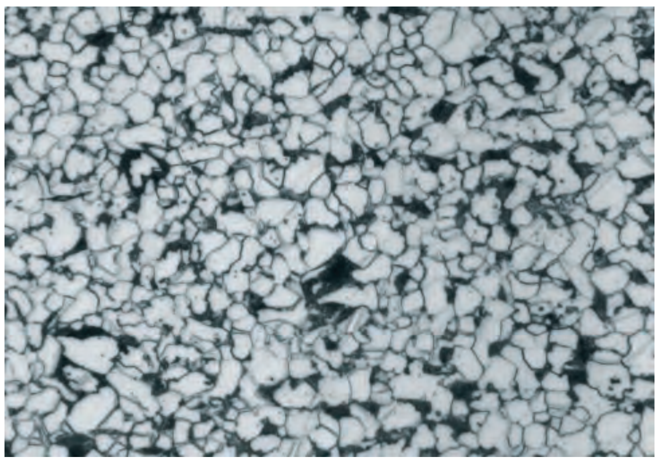

Fig.20 HAZ 2 of air cooled (50X)

pearlite and bainitic formation.

MICROSTRUCTURE OF HEAT AFFECTED ZONE

Arc welding produces high rise in temperature for the metal to be joined. This causes adjacent material to heat up

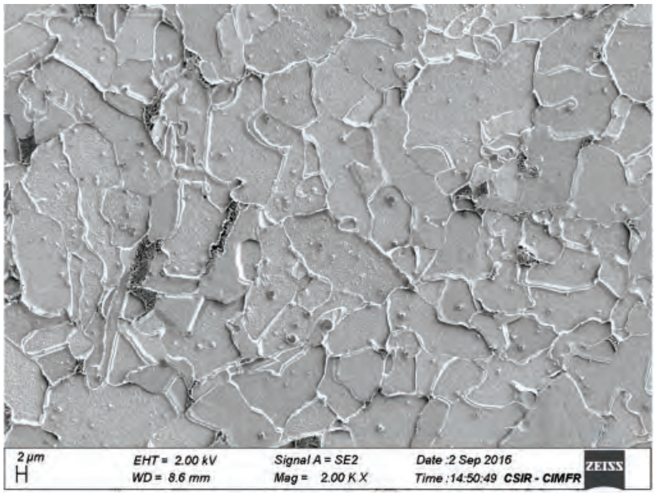

Fig.21 HAZ 2 of air cooled (2KX)

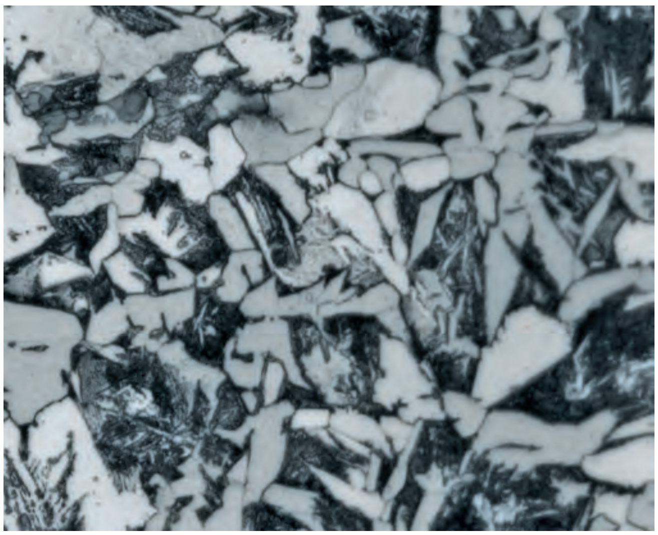

Fig.22 HAZ 2 of transformer oil cooled (50X)

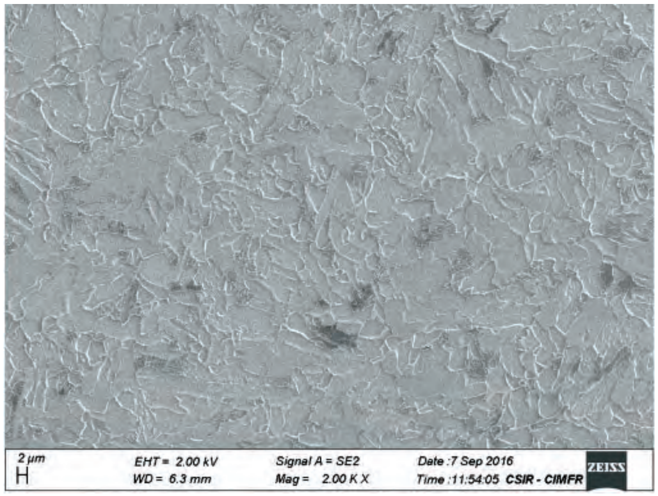

Fig.23 HAZ 2 of kerosene oil cooled (2 KX)

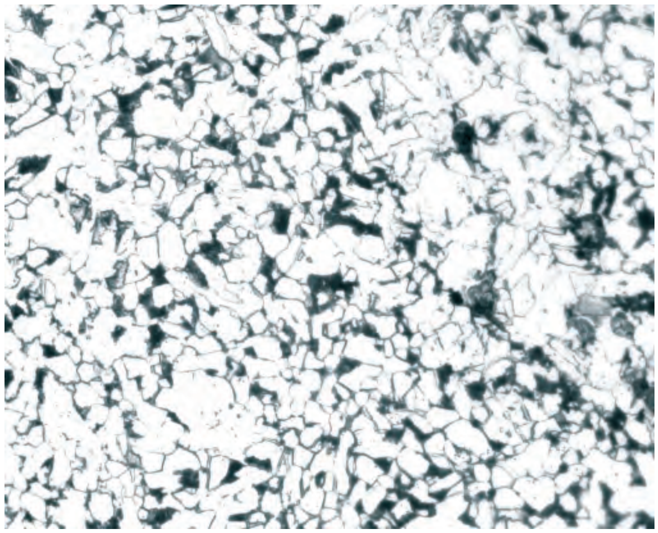

Fig.24 HAZ 2 of kerosene oil cooled (50X)

known as heat affected zone (HAZ). Here the heat affected zone from the metallographic point of view has been further subdivided into three distinct zone i.e. (i) HAZ 1 which is adjacent to weld zone (7mm), (ii) HAZ 2 which is 15mm away from the weld zone and (iii) HAZ 3 which is near to the parent metal (Fig.1). After welding and joining the two rods, cooling has been carried in air, transformer oil, kerosene oil and water. The microstructure and hardness of the sample of the above three zones under different cooling media have been carried out. The microstructures of the samples have been reported in (Figs.11-33).

In the HAZ 1, the air cooled sample has been observed as 63% of ferrite along with 37% of pearlite (Figs.11 and 12) and whose average hardness is measured to be 161 BHN. The transformer oil cooled sample has 23% ferrite comprising of grain boundary ferrite and Widmanstatten (WD) ferrite (Figs. 13-15) and rest 77 is upper bainite. The combination of Widmanstatten ferrite and upper bainite has resulted in good hardness of 187 BHN. In kerosene oil cooled sample, the ferrite percentage is 67% and the rest 33% is pearlite (Figs.16 and 17) and its hardness value measured is 177 BHN. Water cooled sample consists of 65% ferrite and rest 35% martensite (Figs.18 and 19) and due to the formation of martensite its hardness is more than the other samples which is 210 BHN.

Micro structure of heat affected zone (HAZ 1)

In the HAZ 2, the air cooled sample having 46% of ferrite along with 54% of pearlite (Figs.20 and 21) and its hardness value is 195 BHN. While the transformer oil cooled sample contains coarse ferrite of 35% and 65% bainite (Fig 22). The hardness of the sample is measured as 229 BHN. In kerosene oil cooled sample, the ferrite percentage is 66% and the rest 34% is pearlite (Figs.23 and 24) and its hardness value measured as 215 BHN. The water cooled sample consists of 72% ferrite and rest 28% martensite (Figs.25 and 26). Its

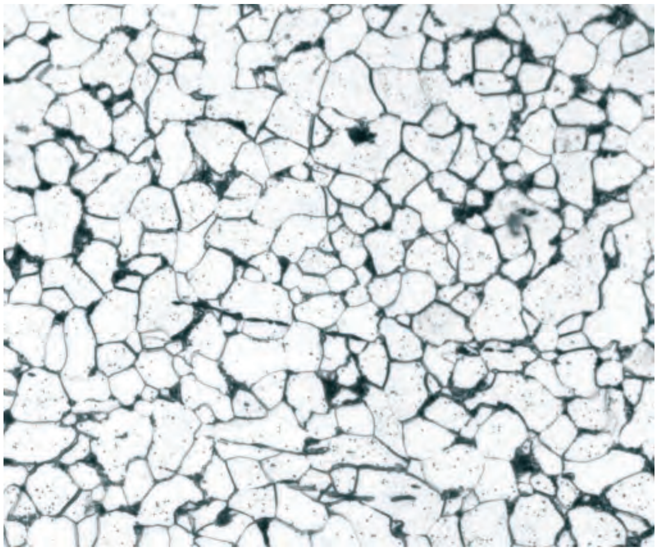

Fig.25 HAZ 2 of water cooled (50X)

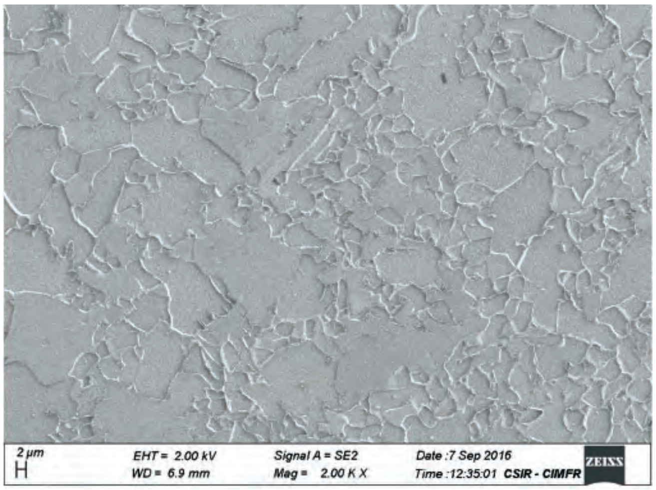

Fig.26 HAZ 2 of water cooled (2KX)

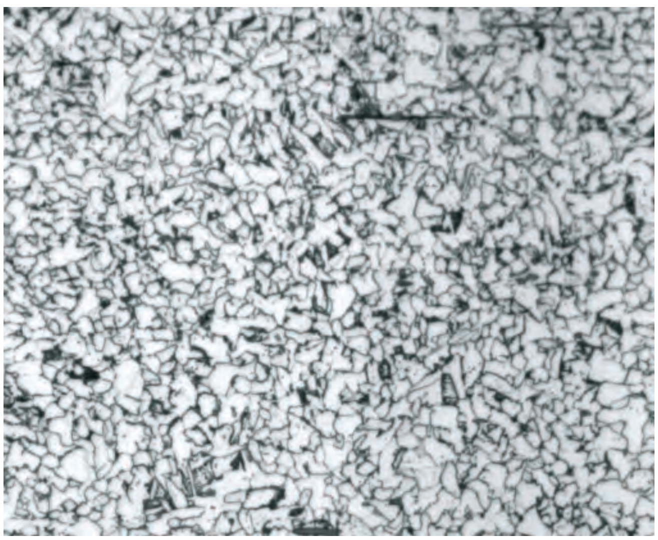

Fig.27 HAZ 3 of air cooled (50 X)

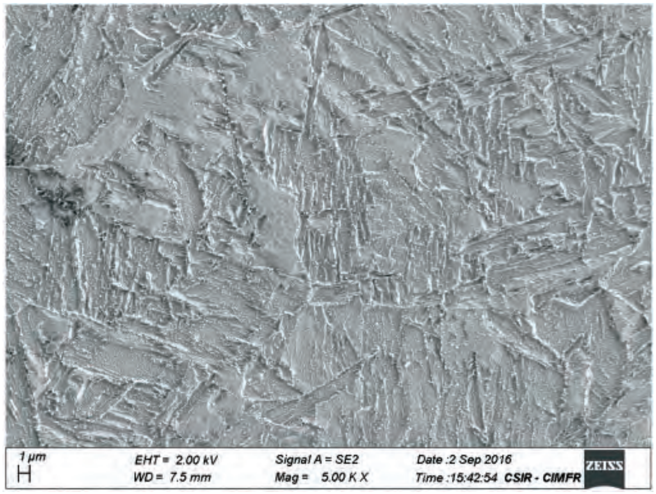

Fig.28 Degenerated bainite of HAZ 3 of air cooled (5KX)

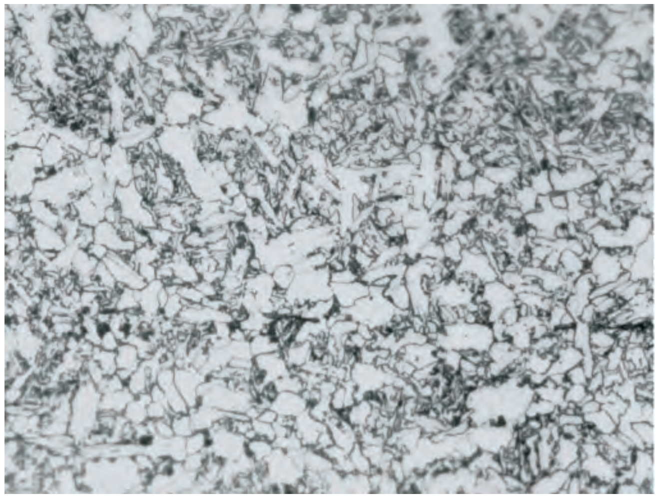

Fig.29 HAZ 3 of transformer oil cooled (50X)

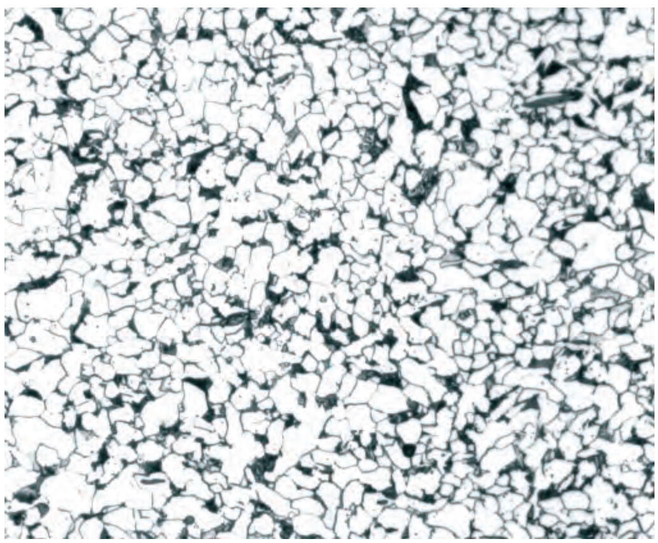

Fig.30 HAZ 3 of kerosene oil cooled (50X)

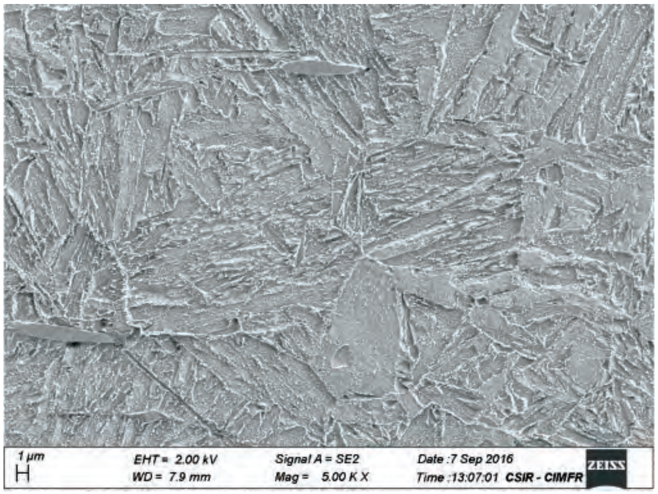

Fig.31 HAZ 3 of kerosene oil cooled (2.5X)

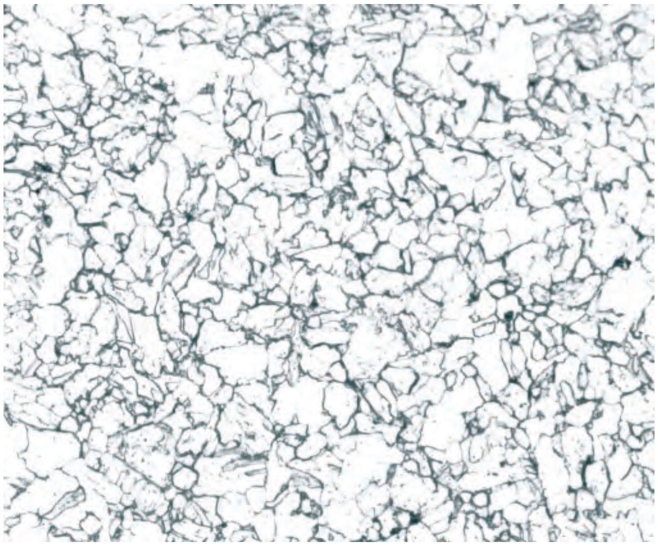

Fig.32 HAZ 3 of water cooled (2KX)

hardness is nearer to the base metal which is 262 BHN.

Microstructure of heat affected zone (HAZ 2)

In HAZ 3, the air cooled sample consists of 62% of ferrite along with 38% of bainite (Figs.27 and 28) and its hardness value is 229 BHN. The sample also observed degenerated bainite along with coarsening of carbide in the transition zone between parent and HAZ 3 (Fig 28). While the transformer oil cooled sample contains ferrite of 68% and 32% bainite (Fig 29). The hardness of the sample is measured as 239 BHN. The kerosene oil cooled sample contains 62% ferrite and the rest 38% is degenerated bainite (Figs.30 and 31). Its hardness value measured is 239 BHN. Water cooled sample consists of an unstructured matrix of tempered martensite with very small, uniformly distributed carbides, and a certain amount of residual austenite. The content of retained austenite should be around 20% (Figs.32 and 33). Its hardness is more than the base metal which is 270 BHN.

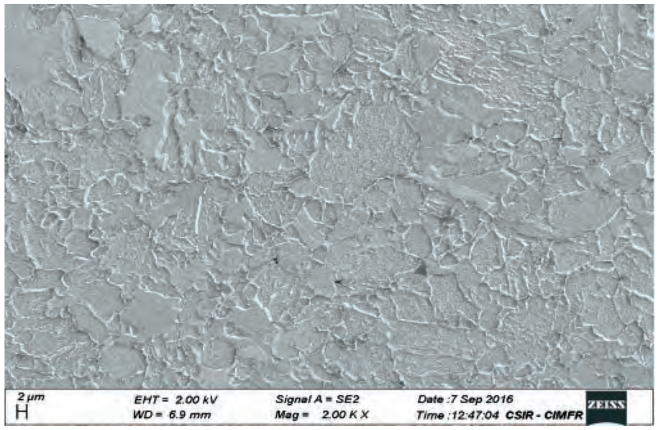

Fig.33 HAZ 3 of water cooled (2KX)

Microstructure of heat affected zone (HAZ 3)

A brief summary of different phases and their hardness under different cooling medium is given in Table 3.

TABLE 3: BRIEF SUMMARY OF STRUCTURE AND HARDNESS OF DIFFERENT ZONE

Zone	Cooling medium used	Microstructure	Hardness in BHN
HAZ 1	Air	Ferrite - 63% Pearlite - 37%	161
	Transformer oil	Ferrite - 23% Upper bainite - 77%	187
	Kerosene oil	Ferrite - 67% Pearlite - 33%	177
	Water	Ferrite - 65% Martensite - 35%	210
HAZ 2	Air	Ferrite - 46% Pearlite - 54%	195
	Transformer oil	Ferrite - 35% Bainite - 65%	229
	Kerosene oil	Ferrite - 66% Pearlite - 34%	215
	Water	Ferrite - 72% Martensite - 28%	262
HAZ 3	Air	Ferrite - 62% Bainite - 38%	229
	Transformer oil	Ferrite - 68% Bainite - 32%	239
	Kerosene oil	Ferrite - 65% Bainite - 35%	239
	Water	Ferrite - 63% Martensite - 39%	270
Parent		Martensite Retained austenite ~ 20%	266

4. Conclusion

Following conclusions can be drawn on microstructural changes of arc welded and heat affected samples under varying cooling media.

1. The microstructure of weld zone and heat affected zones varies under different cooling medium.
2. The weld zone for air and kerosene oil cooled samples shows formation of ferrite and pearlite whereas, transformer oil cooled samples shows formation of ferrite and pearlite with some bainite having good hardness and toughness.
3. Weld zone should be cooled with transformer oil which may give good structure and hardness.
4. In HAZ 1 and HAZ 2 also have similar type of structure as in weld zone. The formation of ferrite and bainite in transformer oil cooled sample has been observed from HAZ 1 to HAZ 3 samples along with good hardness.
5. It has been observed that grain size has been reduced as we move from HAZ 1 to HAZ 3. The refinement of grain size from HAZ 1 towards HAZ 3 has resulted in increase in the hardness value
6. Hardness of water cooled sample is found to be always high in weld zone and heat affected zone samples due to formation of martensite which is brittle in nature. Hence water should be avoided for cooling purpose.
7. The transformer oil cooled sample is found to be good structure in combination with hardness and toughness as well.

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