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Comparative Study of Properties Developed In Microwave And Conventional Heating of En-9 Steel.

[1] Abhijeet AP [2] Manjit MK [3] Utkal SP [4] Sunil SJ [5] Ravindra IB
[1][2][3][4]Sharad Institute of Technology College of Engineering, Yadrav-Ichalkaranji

***Abstract*:-- Present work deals with the comparison of mechanical and metallurgical characteristics developed in EN-9 steel specimens subjected to heating at recrystallization temperature followed by subsequent cooling in oil, water and air. Heating of EN-9 steel specimens is carried out using microwave radiation as well as conventional heating technique. Characterization of post heat treated specimens is carried out using universal testing machine, hardness tester, optical microscope and scanning electron microscope. Microwave heated specimens exhibit better mechanical properties compared to that of conventionally heated specimens. Further, it is observed that recrystallization temperature in microwave heating was achieved in 15 minutes whereas in conventional heating the same was achieved in 136 minutes with higher power consumption. The work establishes the basis for potential of heating bulk materials, which is eco-friendly and significantly fast.**

***Keywords:* Microwave heating, susceptor, volumetric heating and recrystallization temperature**

I. INTRODUCTION

EN-9 steel is used for transmission shafts, hand tools, automobile axles and many other applications. These applications require that the components to be subjected to appropriate heat treatment process before they are put into operation. Conventionally, heat treatment is carried out in furnaces that make use of oil, gas or electricity consequently which consume significant amount of energy as well as time. As recent advances in manufacturing industries are towards better and efficient manufacturing techniques, a new process is to be called for that has a potential to produce improved mechanical properties in the components with reduced time and costs.
The use of microwave energy for processing of materials is one of the latest developments that provides clean, rapid and efficient heating over a wide range of temperatures compared to conventional methods of heating. Microwaves are electromagnetic waves in the frequency band from 300 MHz (3×108cycles/second) to 300 GHz (3×1011cycles/second). There is growing interest in the use of microwave energy to process materials. The most important characteristic of microwave heating is volumetric heating, where the heating takes place from inside towards the surface of the material which is quite different from conventional heating where the heating is in reverse direction. Volumetric heating associated with microwave processing results in rapid, controlled, selective and uniform heating. In microwave heating, electromagnetic energy is directly transferred to and absorbed by the material being heated. Further this energy is converted into heat energy within the material and thus provides saving in the energy[1, 2].

Early research work reveals that microwave energy can be efficiently used for sintering of ceramics [3-4]. Later many researchers have used microwaves for sintering commercial metallic powders of various compositions [5-8]. Recently joining of bulk metallic materials has been carried out successfully for joining similar and dissimilar metals [9-13]. Researchers have also successfully investigated melting and casting possibilities using different metals and alloys through microwave energy [14, 15]. However, very limited work has been reported in the area of heating bulk metals using a multimode domestic microwave system.

Application of microwave energy for heating of bulk metals is a challenging area of research owing to reflection of electromagnetic waves by metals at room temperature. Although microwave can heat many materials; certain difficulties are encountered in heating metals and alloys. Microwaves cause sparking of metallic materials and most metals are known to reflect microwaves, as their skin depth is of the order of few microns [10].

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In the present work bulk EN-9 steel is heated to 875^0Cusing microwave hybrid heating technique and cooled to room temperature employing different cooling rates. Characteristic properties developed thereafter by the metal are compared with that of the same material processed by conventional heating in muffle furnace.

II. EXPERIMENTATION

EN-9 steel is one of the most widely used materials in automobile and ancillary industries. Specimens prepared from EN-9 steel were heated by two different modes of heating (i) microwave radiation with power of 700W at 2.45GHz frequency and (ii) conventional heating using muffle furnace with power of 3500W to attain the recrystallization temperature. The specimens were then quenched by three different methods through oil, water and air to study and compare the mechanical properties developed after processing through microwave and conventional heating. Tables 1 and 2 show the mechanical properties and chemical composition of as-received EN-9 steel bar stock respectively. Tables 3 and 4 present the specifications of the multimode microwave oven and muffle furnace used in the experiment respectively. Tensile specimens of EN-9 steel as per ASTM-E8 standard were prepared as indicated in Figure1. Uniaxial tensile test was carried out with universal testing machine (Make: FIE, Ichalkaranji).

Table 1: Mechanicalproperties of As- received EN9 steel

Yield stress MPa	Ultimate tensile stress MPa	Hardness BHN
335	710	210

Table 2: Chemical composition of EN9 steel

Carbon	Silicon	Manganese	Sulphur	Phosphorous
0.50%	0.25%	0.70%	0.05%	0.05%

Table 3: Microwave oven specification

Model	Kenstar
Capacity	17 litres
Power output (MW)	700 Watt
Dimensions (cm)	44 x34x25.8
Weight	10.5 kg

Table 4: Muffle Furnace specification

Manufacturer	Biotechniques India
Volt (V)	230
Watts(W)	3500
Model	BTI

Figure 2 shows the schematic of the microwave setup used in the present work. It is a known fact that all metals reflect microwaves due to very shallow skin depth of the order of few microns at room temperature[8]. In order to overcome this problem, microwave hybrid heating technique is used. The specimens were covered with SiC susceptor, for initial coupling of microwaves with bulk metal. To minimize the heat losses the samples were placed in an insulation box as shown in Fig 3(a).Provision for measurement of temperature by thermocouples was introduced in the setup.

Figure 1: ASTM E8 standard tensile specimen

Three identical specimens were heated in microwave oven to a temperature of 875^0C and soaking period of 20 minutes was allowed. The same experiment was repeated with muffle furnace. The time required to achieve this temperature was recorded as 14 minutes and 130 minutes in microwave oven and muffle furnace respectively.

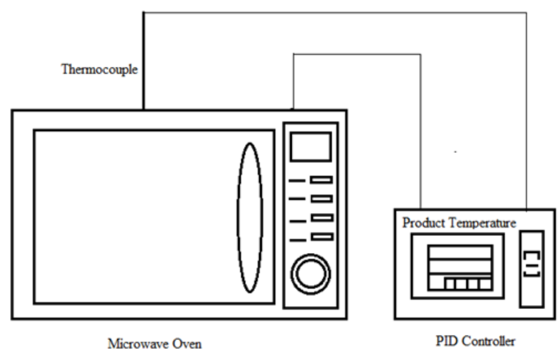

Figure 2: Schematic of microwave oven connected with PID controller

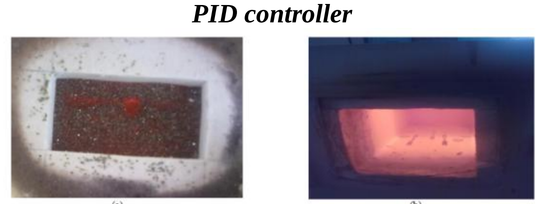

Figure 3: Photograph of red hot specimen (a) microwave heated inside the insulation box covered with SiC (b) muffle furnace

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After heating, first specimen was cooled in air, second specimen was oil quenched and the third specimen was water quenched. The same procedure was repeated for the samples heated in muffle furnace. To ensure repeatability second trial with another set of three specimens was prepared and subjected to heating as above. Table 4.3 shows the strength and hardness values obtained after two trials in MW heating and MF heating. Figure3 shows the red hot zone at 875^{0}C in both the cases.

III. RESULTS AND DISCUSSION

There has been a need for developing faster, accurate and sustainable techniques for heat treatment of engineering materials. Comparison of microwave heating and conventional heating of EN-9 steel specimens is carried out in terms of power input, time and mechanical properties.

3.1 Mechanical characterization

The tensile and hardness tests conducted for the specimen after heating and the results are presented in Table5.

Table 5: Strength and hardness values obtained after experimentation

Sr. No	Process Employed	Type of Cooling	UTS MPa		Hardness BHN	
			Trial 1	Trial 2	Trial 1	Trial 2
1	Microwave heating	Oil quenching	721.50	738.21	578	582
2		Water Quenching	845.33	838.26	554	568
3		Air cooling	901.88	924.23	219	215
4	Muffle furnace heating	Oil quenching	686.51	659.21	586	558
5		Water Quenching	802.36	792.28	576	556
6		Air cooling	866.51	869.58	202	207

From above experimental results, inference can be made that UTS values obtained after testing microwave heated specimens are little higher, which is attributed to the volumetric heating phenomena associated with microwave heating process. On the other hand hardness values observed for microwave heated specimens exhibit similar results with marginal variation as compared to that obtained from conventional heating. Results derived from Trial Nos. 1 and 2 are almost same which indicates the consistency of microwave heating process.

3.2 Metallrugical characterization

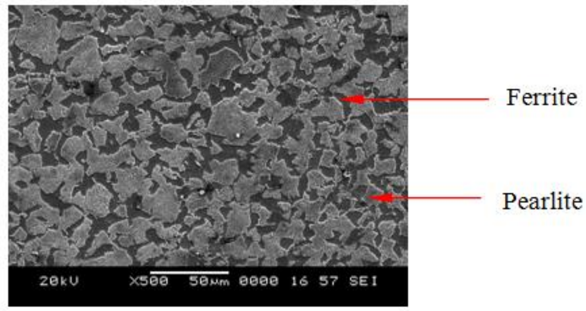

Figure 4: SEM micrograph of as-received EN-9 steel sample

Figure 4 shows the microstructure of the sample before heating which indicates ASTM grain size 7 to 8 with appearance of elongated and equiaxed grains containing 55 to 45% ferrite matrix.

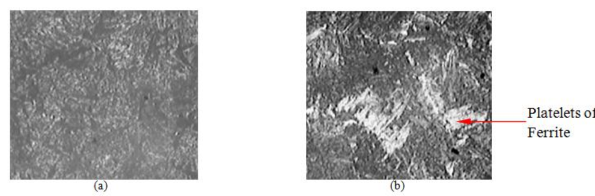

Figure 5: Optical micrographs of oil quenched specimens at 250X (a) Muffle furnace (b) Microwave oven

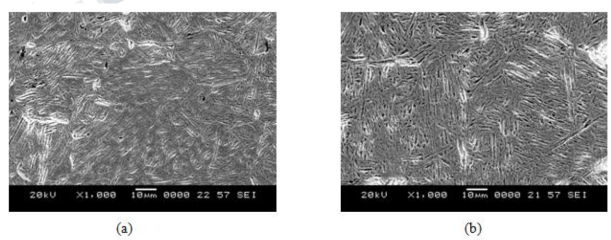

Figure 6: SEM micrographs of oil quenched specimens (a) Muffle furnace (b) Microwave oven

Figures 5(a) and 6(a) show the microstructures of oil quenched specimen from muffle furnace having coarse structure of martensite whereas, Figures5(b) and 6(b) show microstructures of oil quenched specimen processed using microwave heating having fine bainite structure which exhibit better machinability properties. Widmanstatten platelets of ferrite are observed at prior austenite grain boundary and in a matrix of martensite in

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Figures 5(b) and 6(b). This could be due to remarkable difference in the heating rates and also due to the fact that the samples were subjected to volumetric heatingin microwave oven which resulted in bainitic structure.

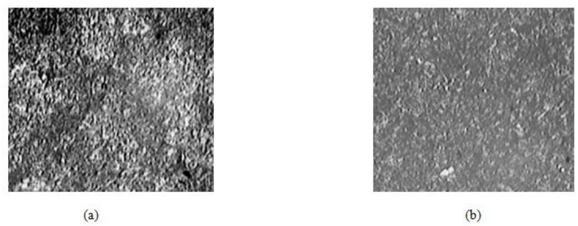

Figure 7: Optical micrographs of water quenched specimens at 250 X (a) Muffle furnace (b) Microwave oven

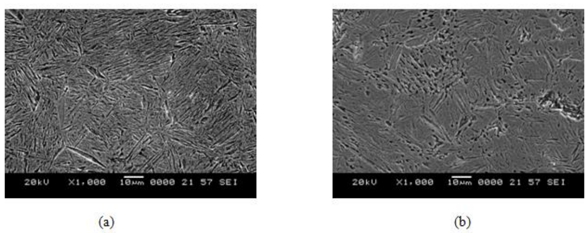

Figure 8: SEM micrographs of water quenched specimens (a) Muffle furnace (b) Microwave oven

Figures7(a) and 8(a) show microstructure of the water quenched specimen from muffle furnace in which coarse martensitic structure is observed. Figures7(b) and 8(b) show microstructure of the water quenched specimen from microwave heating, in which more than 95% martensitic structure with fine grains and high toughness is observed**.**

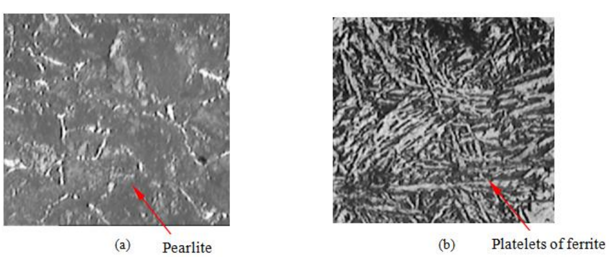

Figure 9: Optical micrographs of air cooled specimen at 250 X (a) Muffle Furnace (b) Microwave heating

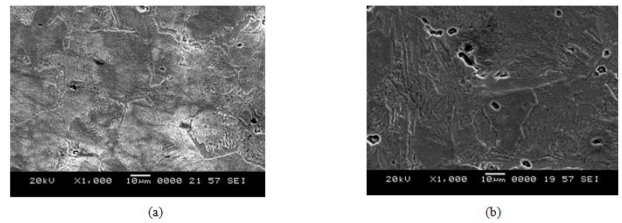

Figure 10: SEM micrographs of air cooled specimen (a) Muffle Furnace (b) Microwave heating

Figures9 (a) and 10(a) show microstructures of the muffle furnace, air cooled specimen, ASTM grain size 7 to 8 elongated and equiaxed. Grains of predominantly pearlitic matrix with grain boundary ferrite are observed. Air cooling requires more time for cooling and therefore grain size reduces. Figures 9(b) and 10(b) show microstructures of the air cooled specimen of microwave heating, Widmanstatten platelets of ferrite at prior austenite grain boundary and matrix of martensite are observed. Coarse microstructure obtained also promotes to improve machinability.

Further, fractography analysis was done for the fractured samples using scanning electron microscope. Figures 11, 12 and 13 show the microstructures of fractured specimens for oil quenched, water quenched and air cooled specimens respectively. Figures 11 and 12 show sheared surfaces which is an indication of brittle fracture as a result of increased hardness due to rapid cooling. On the other hand Figure 13 exhibits small dimples which constitute ductile fracture that has occurred due to significant plastic deformation the specimens have experienced prior to their failure. However, it is also observed from microstructures in Figures 11, 12 and 13 that samples prepared by heating in muffle furnace and microwave oven fail in similar manner.

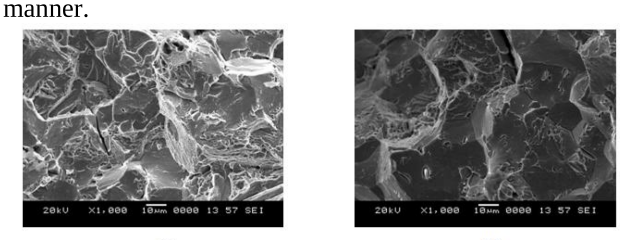

Figure 11: SEM micrographs of fractured oil quenched specimens (a) Muffle Furnace (b) Microwave oven

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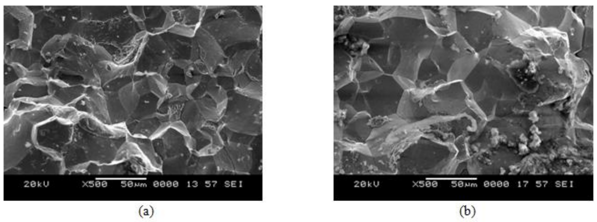

Figure 12: SEM micrographs of fractured water quenched specimens (a) Muffle Furnace (b) Microwave heating

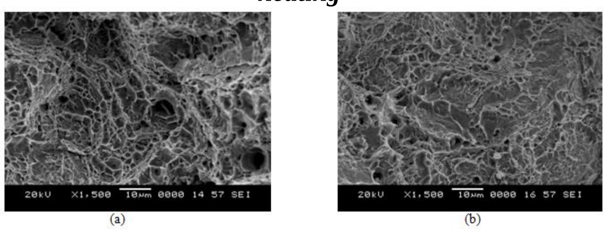

Figure 13: SEM micrographs of fractured air cooled specimens (a) Muffle Furnace (b) Microwave heating

IV. CONCLUSIONS

The present work highlights the development of microwave hybrid heating process for heating bulk metals. Further development of microwave heating applications is in progress. The work establishes basis for potential of heating bulk materials, which is eco-friendly and significantly fast. The following major conclusions could be drawn from the present work.

1) Metallurgical heating of EN-9 steel in bulk form has been carried out successfully in this work.
2) UTS values found after microwave heating are better than conventional heating which implies that toughness of the samples is increased.
3) No appreciable change is noticed in hardness values of microwave heating.
4) Required temperature (875^{0}C) was attained at a faster rate in microwave heating as compared to conventional heating viz; 15 minutes and 136 minutes respectively.
5) As power consumption is a time factor, power consumed in muffle furnace is higher than in microwave oven, thus energy saving is obvious.

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