

A comparative study on mechanical properties of heat treated steel EN24 and its MMC with SiC

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Received 20 January 2017; accepted 26 September 2017

The investigation has been undertaken to evaluate the mechanical properties of sintered and heat treated EN24 alloy steels by using elemental powders through powder metallurgical techniques. The green compacts obtained through powder metallurgy route have been sintered at $1150 \pm 10^\circ\text{C}$ in vacuum furnace. Silicon carbide content used as reinforcement in EN24 matrix is varied and tensile specimens are prepared. Tensile test specimens prepared from EN24 steel plate is subjected to standard heat treatment. Both Sintered and heat treated EN24 steels are subjected to tensile tests with by 40 Tonn Capacity Hydraulic Universal Testing Machine. Their microstructures are evaluated using optical and electron microscopy. From the data obtained a comparison of the properties of the En 24 composite with heat treated En 24 steel has been attempted.

Keywords: Steel EN24, Heat treatment, Powder metallurgy, Hardness

Metal matrix composites (MMCs) are fabricated by the combination of metal (matrix) and hard particles (reinforcement)¹. Steel based metal matrix composites (MMCs) exhibit high hardness, high impact toughness, dynamic strength and fracture toughness^{2,7}. MMC materials based on steel matrix with SiC as reinforcement particles⁹ have just such characteristics. The optimal content and disposition of SiC particles in the steel combine extreme hardness and wear resistance^{3,8} with high strength and toughness of metal base. MMCs are gaining widespread popularity in several areas of applications related to automobiles, space, defense, aerospace, and sports segments¹⁰. MMCs are produced by several routes such as powder metallurgy, squeeze casting, stir casting, and infiltration techniques. Composite prepared by powder metallurgy technique^{7,11} have better properties when compared to composite made by liquid metallurgy. The mechanical behavior of the composite depends on the matrix material composition, size and weight fraction of the reinforcement and method utilized to manufacture the composite. The distribution of the reinforcement particles in the matrix alloy is influenced by several factors such as mixing method, type of binder used, method of compaction, the way it is

sintered, sintering temperature¹², interaction of particles and the matrix before, during, and after mixing. Non homogeneous particle distribution is one of the greatest problems in preparation of metal matrix composites. The promising powder metallurgy technique utilized to fabricate the composites¹³. The process is simple, flexible, and applicable for mass production and it is also helpful in producing high density products. Mixing of powders is defined as the thorough blending of reinforcements and matrix alloy powders into same nominal composition with the uniform distribution of reinforcements. A billet is formed by either hot pressing in vacuum or hot isostatic pressing. A solid binder like zinc stearate is used to improve the green strength of the specimen. Heat treatment is also one of the ways to improve the hardness of the heat treatable alloy steels; the hardness of the specimen depends on the quenching medium, temperature⁵. In this work the quenching medium as a cotton seed oil is heated to different temperatures⁶ and different quenching liquids, viz, ISO Max166, ISO Rapid451 and ISO Dur450 used for heat treatment.

Fabrication of EN24/SiC Composite

Mixing of steel En24 and SiC powder

The steel and SiC powder were mixed together before compaction to ensure uniform distribution^{7,14}.

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A pestle motor of dimension 4 inches was used for the mixing purpose. Along with these powders zinc stearate^{11,15} was also used to ensure that the powder doesn't stick to walls of die and punch while the compaction takes place. Different proportions of steel and SiC were used along with 2 g of zinc stearate and were thoroughly mixed for uniform distribution for around 20 min in the pestle motor. The different compositions that used were 2%, 4%, 6%, 8% and pure steel EN24 powder with 2 g of zinc stearate for all combination.

Compaction of the powder

Compaction metal die is cleaned by using acetone to remove impurities. Pre mixed and measured powder is then placed inside the die and compacted by using a 40 Ton hydraulic UTM in room temperature, different loads were tried in order to optimise the better loading condition, after several attempts its fixed to 20 tons. Compaction load is maintained for 2 min and then green pellet is ejected out safely from the die. The metal die set for compaction, compacted specimen ejection and compacted green specimen are shown in Figs 1, 2 and 3, respectively.

Sintering

The green pellets were sintered by placing inside a vacuum furnace to a temperature of 1150°C at the rate of 5°C/min¹⁶. The pellets were held at that temperature for 2 h, heated specimens¹⁷ were allowed to cool inside the furnace almost for after 24 h. The sintered specimen is shown in Fig. 4.

Heat treatment

Steel EN24 plates as supplied condition is subjected to heat treatment in two stages.

(i) Quenched in a cotton seed oil at different temperatures : the steel EN24 plates were heated to a 840°C in a vacuum furnace and immersed into a cotton seed oil which is kept at different temperatures⁸, viz, 25°C, 50°C, 75°C and 100°C.

(ii) Quenched in different oil baths: the steel EN24 plates were heated to a 840°C in a vacuum furnace and immersed into a different quenching oil baths, viz, ISO Max166, ISO Rapid451 , ISO Dur450, and cotton seed oil kept at room temperature.

Results and Discussion

Various tests were conducted on steel EN24 specimens prepared by both powder metallurgy and heat treated as supplied plates in different quenching methods.



Fig. 1 — Metal die set for compaction



Fig. 2 — Compacted specimen ejection



Fig. 3 — Compacted green specimen



Fig. 4 — Sintered specimen

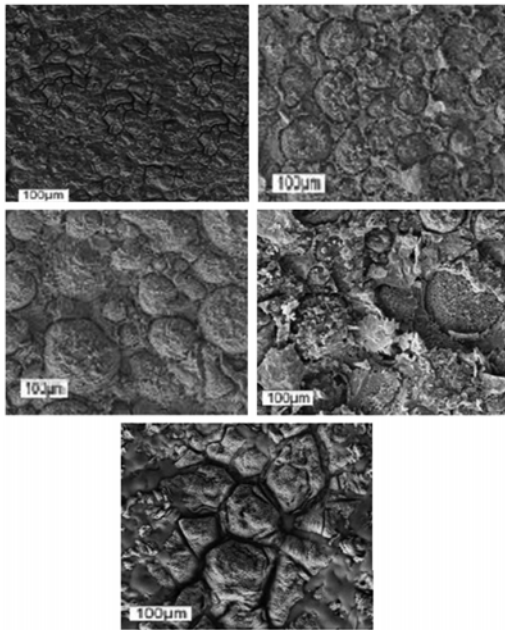


Fig. 5 — Microstructure of sintered specimens

Table 1 — Microhardness of powder metallurgy specimens

Sl. No.	Specimen composition	BHN
1	Steel En24	287
2	Steel En24 +2%SiC	302
3	Steel En24 +4% SiC	325
4	Steel En24 + 6 % SiC	330
5	Steel En24 + 8 % SiC	315

Table 2 — Microhardness for quenched in cotton seed oil at different temperatures

Sl. No.	Quenching medium	Quenching temperature, °C	Microhardness value
1		25	300
2	Cotton seed	50	272
3	oil	75	265
4		100	257

Table 3 — Microhardness of EN24 in different quenching oil at room temperature

Sl. No.	Quenching medium	Quenching temperature	Microhardness value
1	ISO Max166		270
2	ISO Rapid 451	Room	310
3	ISO Dur 450	temperature	275
4	Cotton seed oil		300

Hardness

The hardness test was performed for 3000 kgf load and three trials were performed for all the

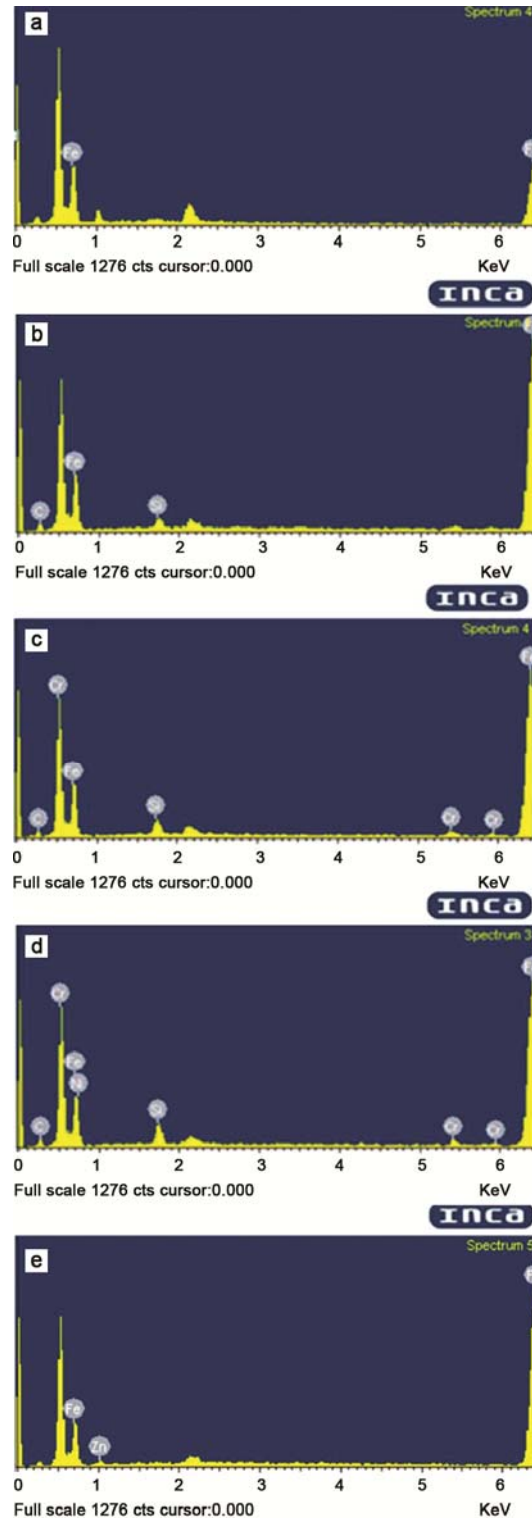


Fig. 6 — EDS of (a) steel En24, (b) steel En24+ 2%SiC, (c) steel En24 +4%SiC, (d) steel En24+ 6% SiC and (e) steel En24+ 8% SiC

specimens and their average values are given in Tables 1-3. The hardness test was performed Brinells hardness tester⁶.

SEM analysis

The SEM analysis was conducted on the samples after they were polished properly and etched. The results of different compositions were determined and are shown in Fig. 5. The SEM images confirm the uniform distribution of SiC particles within the matrix EN24 steel.

EDS analysis

Energy dispersive spectroscopy (EDS) studies were performed on the samples and the elemental composition of the specimen measured. The EDS of steel EN24 with different SiC compositions is shown in Fig. 6. The results have shown that there are no traces of zinc stearate and specimen prepared by powder metallurgy shown presence of silicon carbide.

Conclusions

Steel EN24 and SiC metal matrix composite is developed successfully by using powder metallurgy technique. The developed composites have exhibited higher hardness in the range of 287BHN to 330BHN. The maximum hardness of 330BHN was obtained for a specimen at 6% of SiC and hardness decreased to 315BHN at 8% of SiC. And this could be attributed enhanced SiC particle size and the consequent particle fracture during tensile test.

Zinc stearate is successfully used as a solid binder during compaction and no traces were seen in EDS test after sintering. SEM studies of developed composites proved homogenous dispersion of SiC particle in steel EN24 matrix. Steel EN24 in as supplied condition is successfully heat treated in various quenching conditions heat treated specimens have exhibited better hardness in the range of 257BHN to 310BHN. The powder metallurgy developed MMCs of steel EN24-SiC shows

a highest hardness of 330BHN against heat treated specimen of 310 BHN.

References

- 1 Clyne T W & Withers P J, *An Introduction to Metal Matrix Composites*, (Cambridge Univ. Press, Cambridge, UK), 1995.
- 2 Bolton J D & Youseffi M, *Powder Metall*, 36(2) 1993.
- 3 Lui Y B, Lim S C, Lu L & Lai M O, *J Mater Sci*, 29 (1994) 1999.
- 4 Charkrabarti A K & Das P P, *J Brit Foundryman*, 67 (1988) 330-334
- 5 ASM International 1991, *ASM Handbook: Heat Treatment*, (American Society for Metals Park, Ohio, USA), 4, 1991.
- 6 El-Bagoury N, Amin Mohammed A, Mohsen Q, *Int J Electrochem Sci*, 6 (2011) 6718-6732.
- 7 Dileep B P, Ravi Kumar V, Mrudula Prashanth, Phanibhushana M V, *Appl Mech Mater*, 592-594 (2014) 255-259.
- 8 Canston R J, Hamill Jr J A & Shah S O, in *Advances in Powder Metallurgy & Particulate Materials*, Vol. 4, compiled by Lawlcy A & Swanson A, (Metal Powder Industries Federation, Princeton, NJ), 1993, 61.
- 9 Wu M, Tsao L, Shu G & Lin B, *Mater Sci Eng A*, 538 (2012) 135-144.
- 10 German R M, *Powder Metallurgy of Iron and Steel*, (John Willey & Sons, Inc., New York), 1998.
- 11 Javanbakht M, Salahi E & Hadianfardnejad M J, *Powder Technol*, 289 (2016) 37-43
- 12 *Hoganas handbook for sintered components: Hoganas iron and steel powder for sintered components*, (Sweden: Hoganas AB), 2004.
- 13 Panchas J M, Vela T & Robisch T, *Ferro-TiC® Metal Matrix Composites for High Performance Tooling and Engineering Applications*, Proc Int. Conf. on Fabrication of Particulate Reinforced Metal Composites, Montreal, edited by Masounave J & Hamel F G, (ASM International), 1990, 245-260.
- 14 Gerald Parent P J O, Iyengar J & Henein H, *Int J Powder Metall*, 29 (4) (1993) 353-66.
- 15 Tomas J, *Chem Eng Technol*, 27(6) (2004) 605-618.
- 16 Padmavathi C, Joshi G, Upadhyaya A & Agrawal D, *Trans Indian Inst Met*, 61(2-3) (2008) 239-243.
- 17 Tandon R & German R M, *Int J Powder Metall*, 34 (1998) 40.
- 18 Parent J O G, Iyengar J & Henein H, *Int J Powder Metall*, 29 (1993) 353-366.