

Evaluation of Mechanical Properties for Nickel Based Steel Produced by Metal Injection Moulding and Sintered Through Conventional and Microwave Method

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Metal injection moulding is a near net shape manufacturing technique. It developed from traditional plastic injection moulding and powder metallurgy process. The process involved mixing of metal powder and binder, injection moulding, debinding and sintering of moulded samples. Microwave process indicated critical consideration towards exceptional highlights, regards to, heating and sintering the various grouping of metals with the huge preferred perspective, control rate, and similarity, low ecological dangers. The samples consist of SS316L+WC-CrC-Ni metal powder and binders, low-density polyethylene (LDPE), paraffin wax (PW), stearic acid (SA) and polyethylene glycol (PEG 600). In the present study, the injection moulded green parts are exposed to high-intensity microwave fields operates at a frequency of 2.45 GHz. for sintering of MIM samples. The whole process time of the microwave-assisted sintering was remarkably less than conventional sintering. The sintering of SS316L+WC-CrC-Ni compact showed better results than those produced by sintering with conventional heating. The current study evaluates the effect of the conventional and microwave sintering on mechanical properties.

1. Introduction

Fundamentally, MIM process comprises of mixing fine metal powders with a thermoplastic binder system producing feedstock. Green parts are created by using conventional injection moulding machines (Loh et al., 2008). The binder allow the formability of fine metal powder during injection moulding process and they are removed in the following debinding stage. The binders are removed from the moulded sample by solvent extraction and thermally in the furnace, to form an open porous 'brown part'. In the MIM process, the debinding step is critical due to further densification process is mainly depends on debinding stage. Suitable sintering conditions would promise pore-free structures that have good mechanical properties, preferably the elimination of the binder would open up pore channels which permit quicker removal of the higher boiling point components. After a thermal debinding slight portion of residual binder in the parts, called backbone, allows the handling of the components when transferred to a sintering furnace, the details of the process as shown in Figure 1 (Chinnathayppal et al., 2018). The final densification process takes place in the sintering stage by removal of residual binder through open pore channels. During sintering, MIM parts are shrinks to their final dimensions. Additional final operations, like machining, secondary operations are optional (Gonçalves 2001). The various applications of MIM components are in gun and armament parts, medical and dental instruments, orthodontic devices, and automotive components are also produced by metal injection moulding in industries include rocker arm fuel injector, turbocharger components.

The microwaves sintering procedure acknowledged for mechanical applications since it is permitting reducing the periods of sintering and the vitality utilized. Unfortunately, the metallic materials are reflecting the greater part of the microwaves that is the reason this set-up was examined just as of late. On account of a metallic powder, it was demonstrated that the microwaves could enter the material by the porosities (Leonelli et al., 2008). By expanding the heating rate, this technique has additionally an impact on the grain size distribution and the mechanical properties (Li et al., 2015).

This examination depends on the correlation amongst regular and microwave sintering of SS316L+WC-CrC-Ni. There is no data about the handling of SS316L+WC-CrC-Ni through these two new approaches. The initial step is to change the sintering parameters of these two techniques by finding the best density while keeping the merits of the MIM procedure with a simple geometry. The microstructures of the sintering temperature will permit looking at the conduct of the material at various heating rates. The impact of this parameter is openly affecting the grain size thus the mechanical properties, so the hardness of the samples is looked.

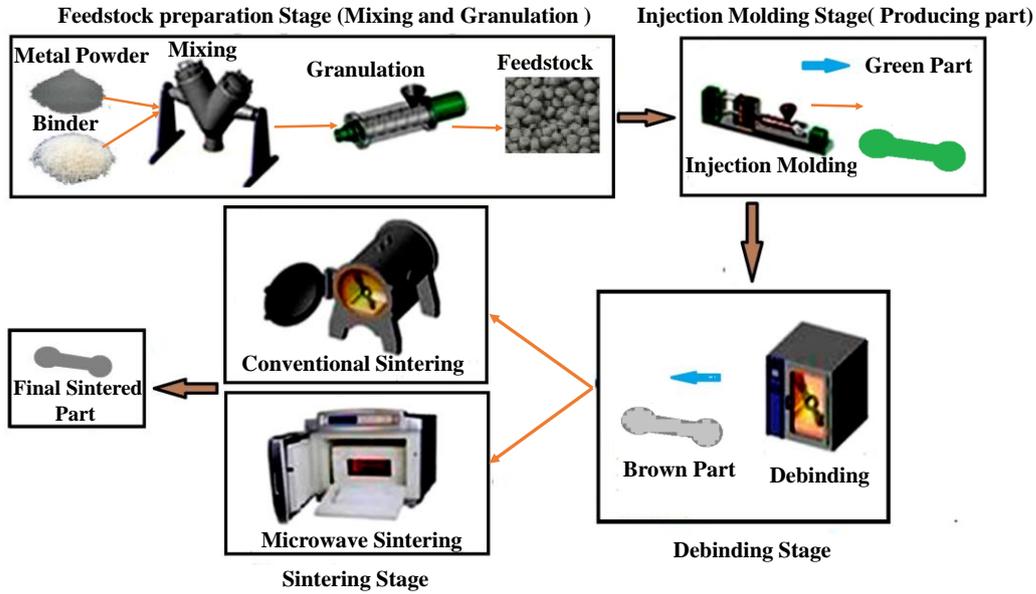


Figure 1: Metal injection moulding processing with microwave sintering

2. Materials and methods

In present study, metallic powders were used SS316L+WC-CrC-Ni. The binder comprises of Polyethylene Glycol 600(PEG 600), Stearic Acid (SA), Paraffin Wax (PW), and Low-Density Polyethylene (LDPE). Figure 2 shows the binders for preparation of feedstock, and composition of the binder and feedstock by weight percentage of its ingredients has been given in Table 1.



Figure 2: Basic materials for preparation of feedstock

The SS316L+WC-CrC-Ni powder is delivered by Innomet powders Hyderabad, India and its chemical composition is presented in Table 2. The particle analyzer was used to measure powder size distribution and the diameter values corresponded to cumulative volume fractions D_{10} , D_{50} and D_{90} are 1.29 μm , 6.31 μm , and 14.31 μm respectively(Murray et al. 2011). The powder shape was measured by Scanning electron microscope (SEM) and it's observed Irregular shape as presented in Figure 3.

Table 1: Details of feedstock Composition for SS316L+WC-CrC-Ni

Sl. No.	Ingredients	Weight%
1	SS316L+WC-CrC-Ni	92
2	PW	4.16
3	PEG 600	0.8
4	LDPE	2.8
5	SA	0.24

Table 2: Chemical Composition of SS316L+WC-CrC-Ni delivered by Innomet powders Hyderabad

Powder	Ni	Cr	Mo	C	WC	Fe
SS316L	12	18	2.5	0.03	-	Remainder
WC-CrC-Ni	6	21	-	5	Remainder	-

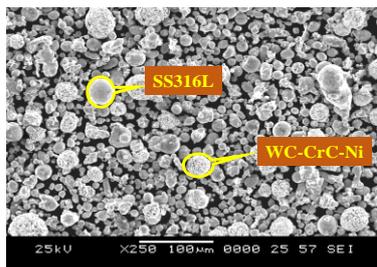


Figure 3: SS316L+WC-CrC-Ni morphology of powder

3. Conventional and microwave sintering

After debinding brown MIM samples are sintered in high vacuum furnace as shown in figure 4(a). The cycle adopted for sintering of MIM specimens heating rate of 1, 5°C/min. The specimen sintered at 1000, 1100 and 1280 °C during 1 hour to achieve the higher level of density. The specimen is then chilled off inside the oven following 5 hours. The density of the specimen is then measured by the utilization of Archimedes' technique (Khairur et al., 2011). They are furthermore etched keeping in mind the end goal to watch the microstructure acquired on a magnifying lens and grains distribution. The Hardness is at finally estimated by a Vickers microhardness test on an Omnitech with a load of 1000 gm.

The specimens are sintered inside a microwave furnace created by V.B ceramics Chennai. The setup is exhibited in Figure 4(b). The energy of the microwaves can be set in the vicinity of 0.10 and 3.0 kW (Saimon et al., 2017). The microwave source permits creating a plasma inside the quartz tube which fills in as a dielectric. The electric field of the microwaves is propagating between the tube and a waveguide giving an electric field consumed by the plasma. This guideline permits the creation and the hold up a plasma section of a specific length, depending on the pressure, the power and the nature of the gas. Contingent upon the gas utilized, a plasma flame can go to high temperature at an extremely quick rate (Palma and Meloni, 2016).

This apparatus was intended to hold up until around 2500 °C. The heating rate and the temperature acquired during sintering are relying upon the length of the flame and the distance from the specimen. With a specific end goal to benefit by the empty spaces left after the polymer is degraded, the MIM specimens utilized during microwave sintering were debinded into the water. The thermal debinding will be done at 500 °C amid 30 minutes under a power below 0.3k and try to restrict the heating rate so as to maintain a strategic distance from over pressure inside the specimen. After the debinding steps, the energy of the microwave source is expanded well-ordered of 100 °C consistently until around 1280 °C during a deliberate time.

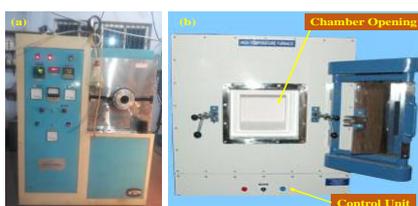


Figure 4: Experimental furnaces a) Conventional b) microwave sintering

4. Results and discussion

4.1 Conventional sintering of SS316L+WC-CrC-Ni sample

In the current investigation, thermal debound brown compacts were sintered. It is the observation that shape starts distorting beyond the formation of the liquid phase of compact (Liu et al., 2008). To avoid oxidation the sintering was carried out pure hydrogen atmosphere at 1280 °C.

In sintering cycle, the heating rate is varied from 1 to 5°C/min and also soaking time is allowed to remove remaining binders in the compact and to stabilize the furnace temperature. To stabilize the furnace temperature the sintering cycle heating rate maintained at 1 to 5°C/min and also soaking time kept for removing binder from the compact. Initially, 2°C/min constant heating rate maintained up to 1000 °C followed by 80 min, 80 min and 30 min soaking time at 250 °C, 400 °C and 1000 °C respectively.

In the following stage 1 °C/min heating rate is kept for densification of specimen till 1000,1100 and 1280 °C, and also 5 °C/min cooling cycle was adopted for 200 °C followed by furnace cooling. The importance of cooling cycle is for avoiding distortion in tensile specimen due to a sudden drop in the temperature.

The MIM specimen sintered at 1280 °C has been shown in Figure 5. It is observed that SS316L+WC-CrC-Ni specimen microstructural characteristic as fishbone structure at dissimilar temperature. The microstructure reveals that isolated pores are separated from the grain boundary and powder particles are bound together at selected temperature and densification of MIM compacts successfully as shown in figure 6(a-c).

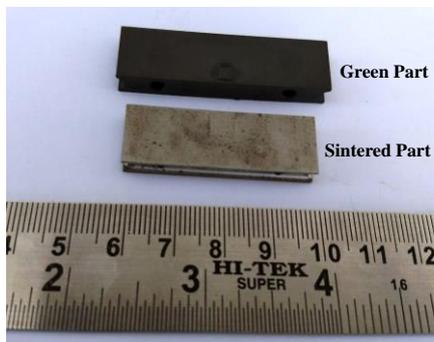


Figure 5: Metal Injection moulded green part and sintered part

An unblemished indication of the nearness of liquid phase during sintering cycle shows up in the specimen, heated up to 1280 °C seeing herringbone morphologies. It can see that the microstructures in Figure 6(a). At 1000°C, beginning to frame necks between the particles. At that point, the grain size varies with the rise in temperature from 12 to 38µm at 1100°C until achieving 48µm at 1280°C. The porosity of the specimen can be seen between the grains.

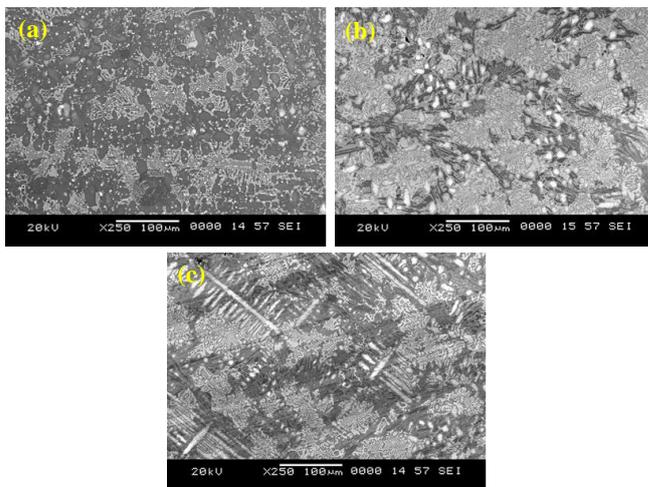


Figure 6: Micrograph of Tool steel T-15 at different sintering conditions: a) 1000 °C b) 1100 °C c) 1280 °C

4.2 Microwave sintering of SS316L+WC-CrC-Ni MIM specimen

The sintering of MIM specimen is carried out in microwave furnace heated up to 1280°C at a heating rate of around 100°C/min. The microstructures of the specimen exhibited in Figure 7. After a sintering time of 30, 40 and 60 min. After 30min, the grain size distribution of the greater grains changes in the vicinity of 20 and 40µm. The development behavior of the grains seems to be like the regular route at a lower temperature (Onbattuvelli et al., 2013). Nevertheless, the proportion between extensive and lower grain isn't the same and could be clarified by a phenomenon effectively saw with different materials. It has been examined the development of hot points on a few specimens took after by a strange growth of the grains. The formations of these points are clarified by reaching locally and brutally a critical temperature where the material begins to stay. An excessively strong energy of the microwaves applied to the material clarifies this phenomenon.

Following 1 hour of sintering, the microstructure looks more homogenous and no more grains are noticeable. A few splits can be seen at first glance. They could be clarified by the debinding step when the heating rate was excessively severe and harmed the shape of the specimen. At the point when the sintering temperature was achieved, the power expected to keep a consistent temperature stayed steady. After a few minutes, more power was required until achieving the utmost of 3kW of the hardware.

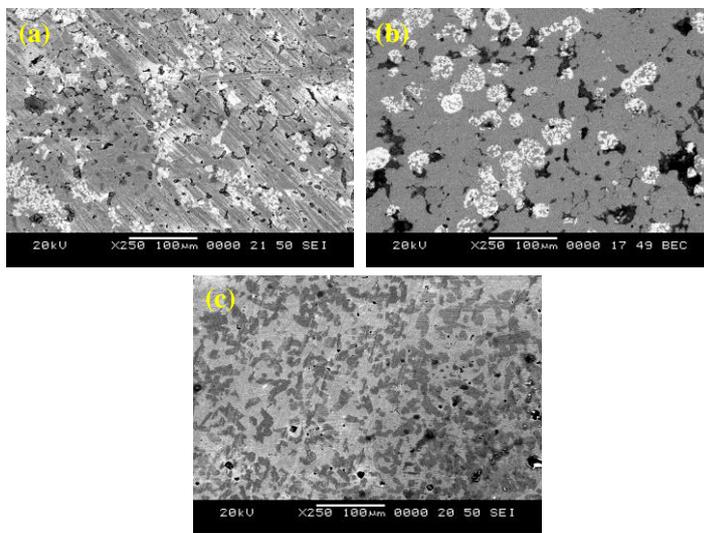


Figure 7: Micrograph of Tool steel T-15 in Microwave sintered conditions: a) 1000 °C, b) 1100 °C, and c) 1280 °C

4.3 The relationship between the two approaches

The density of the MIM specimen sintered conventionally was revealed lower among the two techniques. The microwave sintered specimen reading higher density and hardness in view of the commitment to utilize a low pressure amid the test. There is a probability to enhance it as observed by the density and hardness of the sintered compact only. A quick heating rate and a low sintering time are permitting a better grain size according to the Hall-Petch effect; a lower grain size is inferring better yield pressure abilities (Ferri et al., 2009).

Table 3: Summary results of different sintering methods

Method	Conventional	Microwave
Sample	MIM	MIM
Temperature	1280	1280
Dwell	2h	60 min
Density	92.83%	96.12%
Microhardness (Hv)	689	704

Two variables can clarify this outcome, the first being the splits saw on the surface due to the severe debinding, yet in addition as a result of the hot points framed inside the specimen amid the sintering. As far as energy, the speedier method is the microwave sintering. The sintering time of the SS316L+WC-CrC-Ni is cut significantly between the microwave sintering and the conventional sintering.

5. Conclusions

The formulation of binder combination was successfully working for production of SS316L+WC-CrC-Ni component including debinding, and sintering by conventional and microwave methods.

The behavior of the sintering of SS316L+WC-CrC-Ni in the two distinctive methods of sintering has been inspected. The enhancement of the sintering of SS316L+WC-CrC-Ni powder by Microwave technique is giving a superior hardness than the conventional sintering method on account of a smaller grain size.

The aim of the examination was to attain a MIM specimen by microwave sintering methods while keeping the shape given amid the Injection moulding. It was conceivable to preserve the shape of the specimen while enhancing the mechanical properties. By looking at the outcomes of the different procedures, the microwave sintering is giving the best outcomes. Then again, it is additionally the equipment which is the harder to use with a specific end goal to keep the shape of the moulded specimen. The microwave sintering is giving higher results than the conventional sintering method, however by streamlining the power parameters; it might be less demanding to acquire proportionate properties without having issues with the shape of the MIM specimen.

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