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Effect of die temperature on mechanical properties of hot pressed P/M parts

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Abstract
In conventional warm compaction, both powder and die are heated to a certain temperature during compaction. This is a technique for producing P/M compacts with higher green and sintered strength as compared to room temperature pressing. However, there is a certain limit to powder temperature due to flow problems at higher temperatures. Heating the die above this practical limit can further improve properties. In this work, the effect of die temperature on green and sintered properties of Astaloy CrM powder has been investigated. Here, the powder at 135 ^{o}C was fed to the die at different temperatures. Density and strength for samples in green and sintered conditions were evaluated for two compaction pressures of 500 and 650MPa and temperatures ranging from ranging from 135 to 165 ^{o}C. Comparison of samples compressed at room temperature showed marked improvement in density and strength properties. A 22% increase in density, as well as 40% increase in green strength was observed. Tensile and impact strengths were improved by about 10% and 20% respectively. SEM micrographs showed more rounded pores and hence reduced stress raising sites. The improvement in properties can be mainly attributed to changes in powder morphology and die wall lubrication due to migration of hot lubricant from interparticle space to die walls. The latter will reduce particle spacing and bring about more intimate metal-metal contacts as well as better lubrication on die walls.

Key words: Powder metallurgy, Warm compaction, Sintering, Mechanical properties

1. Introduction

Most of the ordinary P/M parts are normally produced by compaction in solid dies and sintered in controlled atmospheres [1]. In most instances, this production route is ideal for small near net shapes mostly used in automotive industry [2]. However, as a general rule, ordinary P/M parts have some degree of porosity, and therefore are weaker than their wrought counterparts. This shortcoming of the process has been the point of much concern and subject of intensive research since the beginning of commercialization of P/M industry. To this end, considerable effort has been made to reduce porosity (increase density), especially for structural parts. Figure 1 shows this trend since 1960s [3].
As it is seen from Figure 1, increased density can be achieved through the use of improved powders, especially by more favorable morphologies, reduced level of carbon, oxygen and other contaminants, better lubricants and warm compaction [4, 5]. Other methods include surface densification [6, 7], double pressing double sintering [3], and high speed compaction [8, 9].
Since the introduction of warm compaction by Hoeganaes AB in early 1990s [10], this technique has become quite popular in some industrial countries including USA. The powder system and compaction technique proposed by Hoeganaes has been capable of producing iron parts with

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densities exceeding 7.4g/cm^3 by die compaction and single cycle sintering at low temperature (below 1150 ^{o}C) [10].

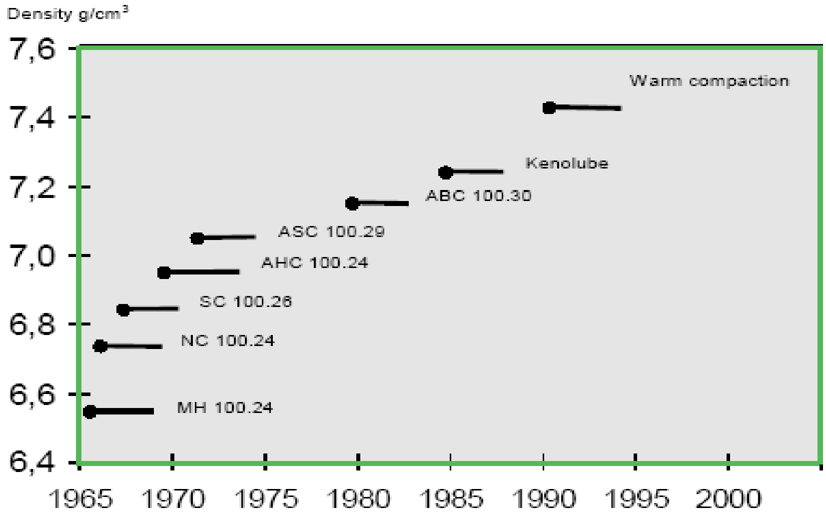


Figure1. 30 years of density improvements in powder metallurgy

This process which utilizes preheated tools [11], yields improved mechanical properties. Here, due to the change in the morphology of the sintered material, higher average densities are obtained. There is also less variation of density within the compact as compared to parts made by conventional press and sintered material. Since the yield strength of the powdered material is reduced at higher temperatures, higher green strength is obtained using the same compaction pressure. For iron powder compacted at 150 ^{o}C, a 3% reduction in yield strength has been reported [12].

Warm compaction may be employed to most powder-material systems. More closed tolerances and improved properties are expected, and due to higher green density, machining of green parts becomes possible. Some of the more important reasons for using this technique are;

- Increasing green density from 0.1 to 0.3g/cm^3,
- Increasing green strength from 50 to 100%,
- Reduced green part defects,
- Improved machinability, and
- Longer tool life due to use of lower pressures.

2. Materials and methods

The material used for this research was Hoeganaes Astaloy CrM. It has been shown that apparent density and flow characteristics of the powder does not vary appreciably at temperatures up to 135^{o}C. However, both apparent density and time to flow increase rather sharply above this temperature. This may cause some scatter in weight of compacts with small changes in temperature [10]. To eliminate this possibility, the powder temperature was kept constant at 130^{o}C, and the die temperature was varied at three temperatures of 130^{o}C, 150^{o}C and 165^{o}C compaction pressure for all samples were 650MPa.

Six 250 watts pen-type heating elements were embedded in the die wall (Figure2).

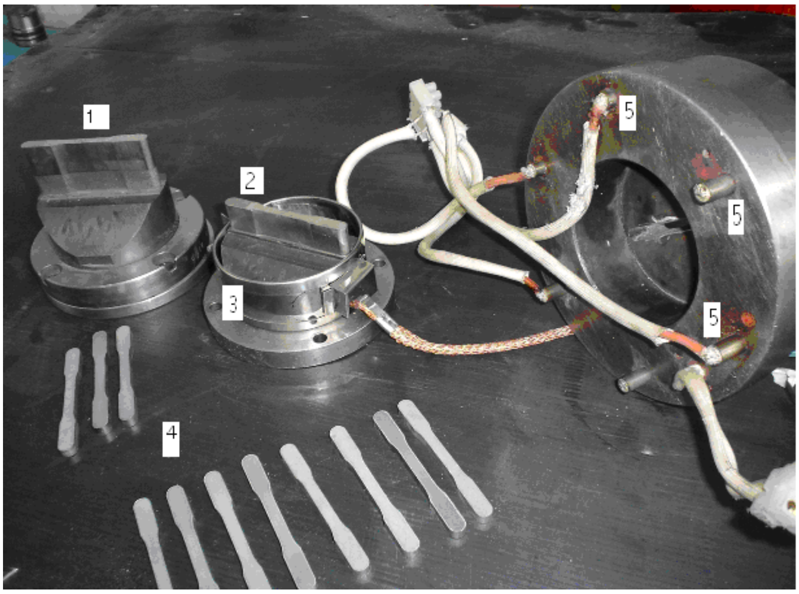


Figure2. Die for preparing of sample tests (1-Uper punch 2-Down punch 3-Band heater 4-Samples 5-Heating accessories)

Dewaxing was done for 20 minutes in pure nitrogen at 600^{o}C, and sintering in $90N_2/10H_2$ atmosphere in a tunnel furnace. Green density was calculated using geometrical methods, while sintered density was measured by Archimedes technique.
Tension test was done according to ASTM E8 in a 250 kN Zwick machine. Three-point bend tests for green and sintered samples were carried out in the same machine. A 50J Charpy machine was used for impact tests.

3. Results and discussion
Figure 3 show that the relative density of the compacts reached 96% of theoretical density at compaction pressure of 650MPa and 165^{o}C die temperature. Such a high green density my be attributed to the rearrangement of the particles due to lateral movement during warm compaction [10]. In conventional cold pressing, there is very little lateral movement of the powder particles, and the dominant mode of particle rearrangement would be through breakage of bridges under uniaxial compaction force.

3.1. Density
Figure 4 and 5 shows variation of density with die wall temperature at two different compaction pressures of 500MPa and 650MPa respectively. These two figures show a linear increase in green density with die temperature up to 150^{o}C, which is good agreement with previous findings [10]. Beyond 150^{o}C, there is little increase in green density. Furthermore, it is observed that the density of samples compacted at 165^{o}C and 650MPa decrease by 0.03g/cm^{3} (from 7.20g/cm^{3} to 7.17g/cm^{3}) after sintering. This may be due to higher strength of the green compact resulting in partial entrapment of gases during evaporation or decomposition of the lubricant.

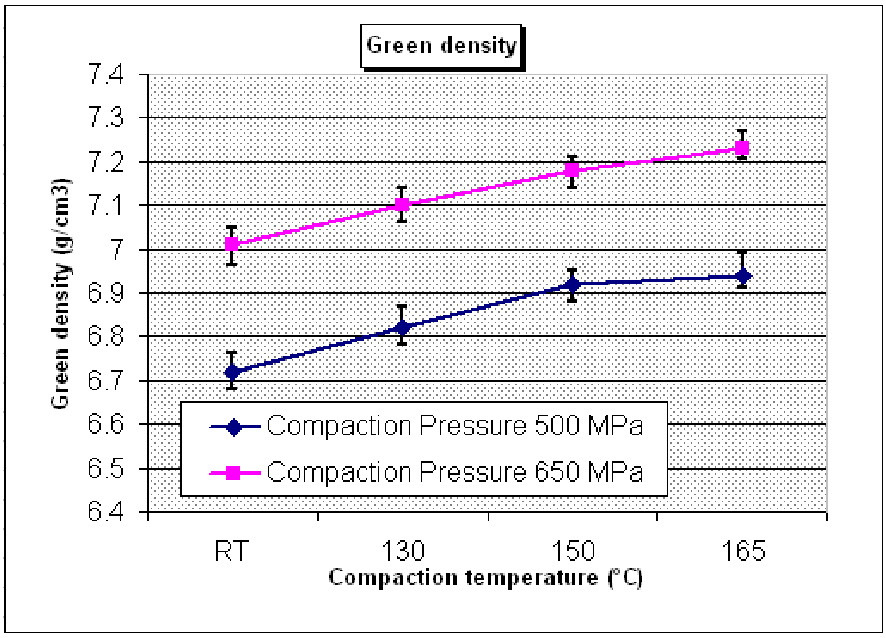


Figure3. Relative density of green samples compacted at 500 and 650 MPa

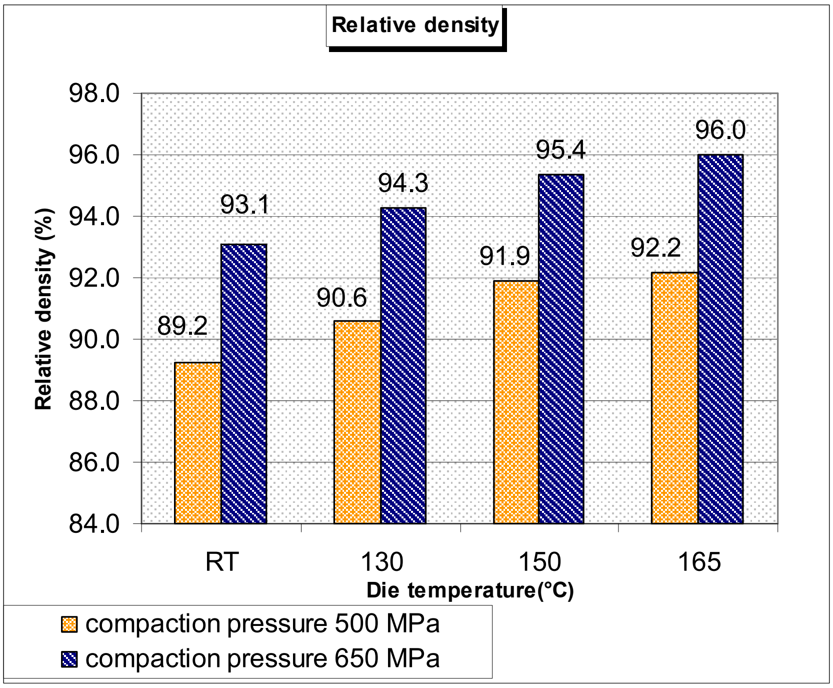


Figure 4. Variation of green density samples with compaction temperature

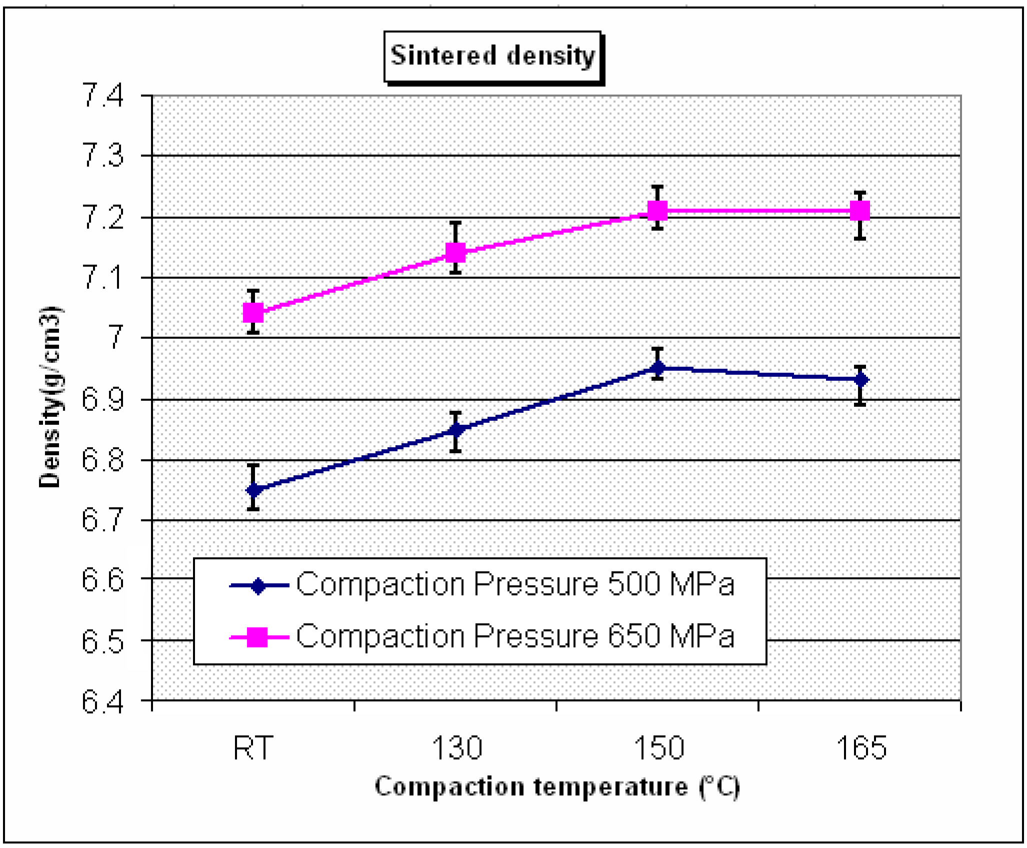


Figure 5. Variation of sintered density samples with compaction temperature

3.2. Green strength

Variation of green strength with die temperature is shown in Figure6. Since increased green density is mainly due to reduction in particle spacing, and creation of a thinner lubricant film, stronger metal-metal bonds are to be expected. Increased green strength with thinner lubricant film has been reported by other investigators as well [10, 13]. Another possibility is movement of lubricant from interparticle spacing towards outer periphery of the powder mass in the die and thus providing a more efficient die wall lubrication [14].
In Figure6, a 40% increase in green density for samples pressed at 500MPa and165^{o}C over ordinary room temperature green compacts is observed.

3.3. Tensile strength

Figure 8 shows changes of tensile strength with die temperature. As shown in this figure, the tensile strength of samples compacted at high temperature is superior to those compacted at room temperature. This can be mainly attributed to increased density (reduced porosity) [15].
Maximum tensile strength was 923MPa as observed for samples compacted at 150^{o}C, which shows a 10% increase over samples compacted at room temperature. Again, beyond 150^{o}C compaction temperature, the strength decreases, which could be due to

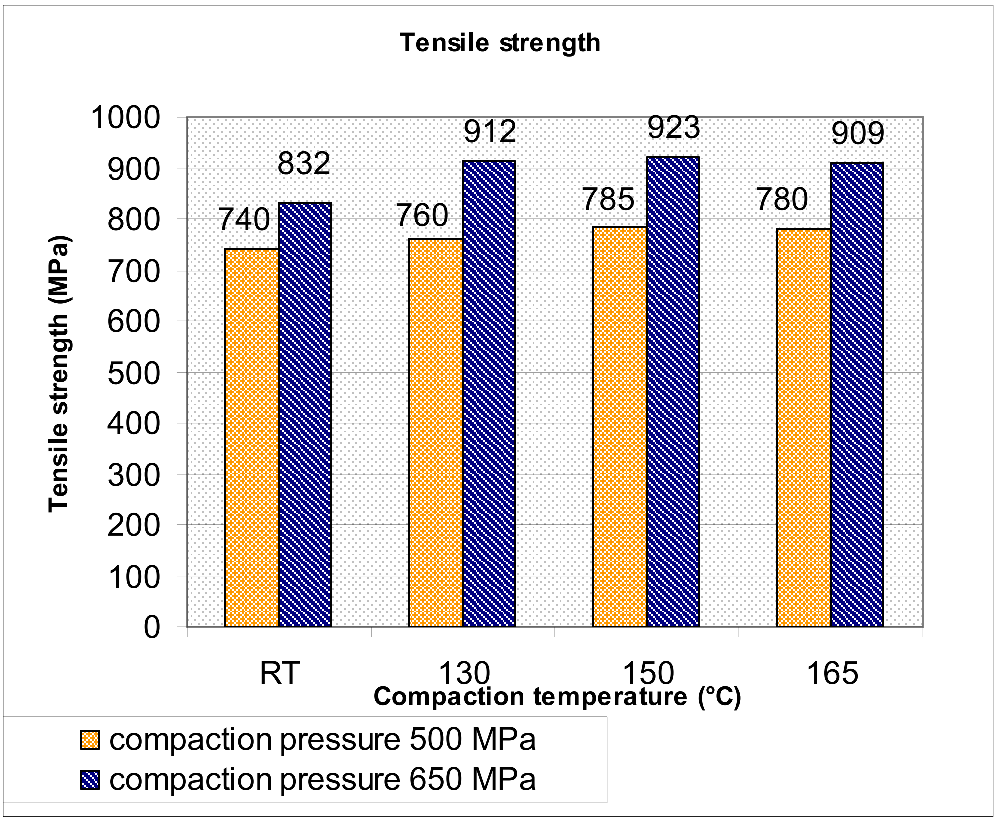


Figure 6. Variation of green strength samples with compaction temperature

entrapment of gases in voids. This phenomenon comes about because of higher strength of the green compacts that hinders escape of gases during evaporation of the lubricant, the result being a reduction in mechanical strength of the sintered product.

3.4. Impact strength

Compaction temperature was found to influence the impact strength of Astaloy CrM samples. Increased impact strength with increasing compaction temperature is again due to reduced porosity and rounding of pores that greatly affect stress concentration, and increased area exposed to impact load. However, as shown in Figure8, maximum energy is observed at 150°C compaction temperature. The reduction of impact strength beyond this temperature (i.e. at 165°C) can be explained by possible entrapment of air pockets due to higher green strength of the samples. Figure 9 shows the morphology and pore distribution for two samples compacted at room temperature and 165°C. Reduced porosity is clearly evident in this figure.

3.5. Fractography

Increased fraction of cleavage areas with compaction temperature is quite evident from fractographs in Figure10

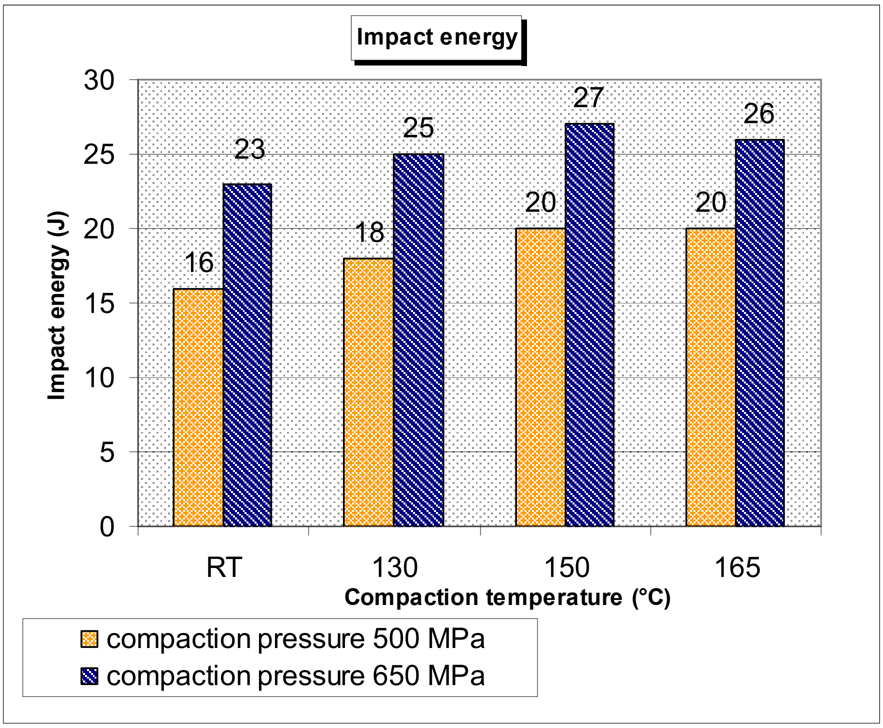


Figure 7. Variation of tensile strength samples with compaction temperature

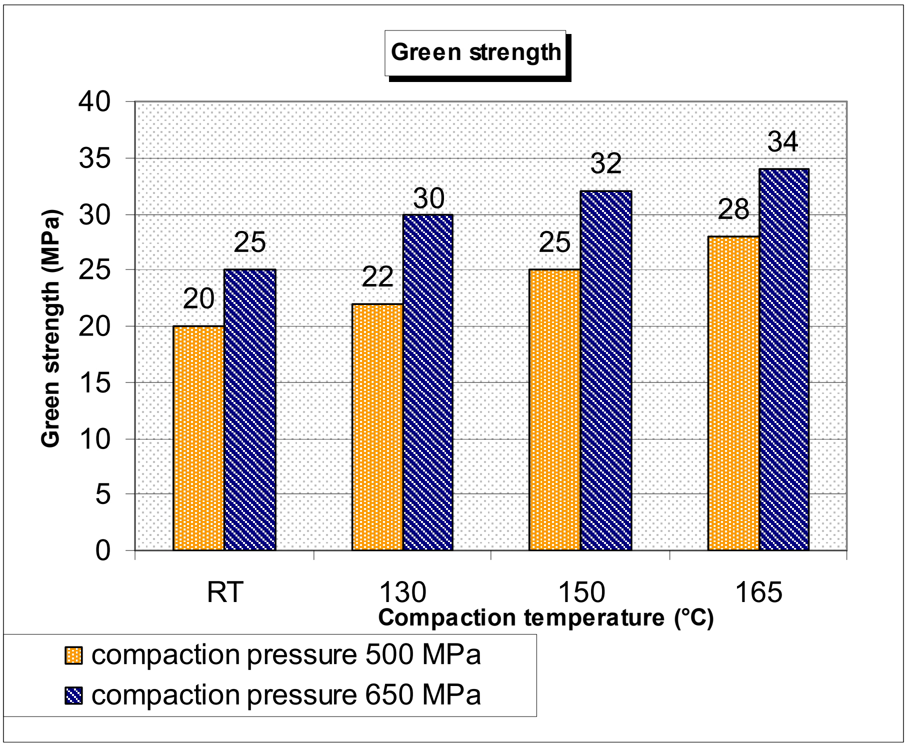
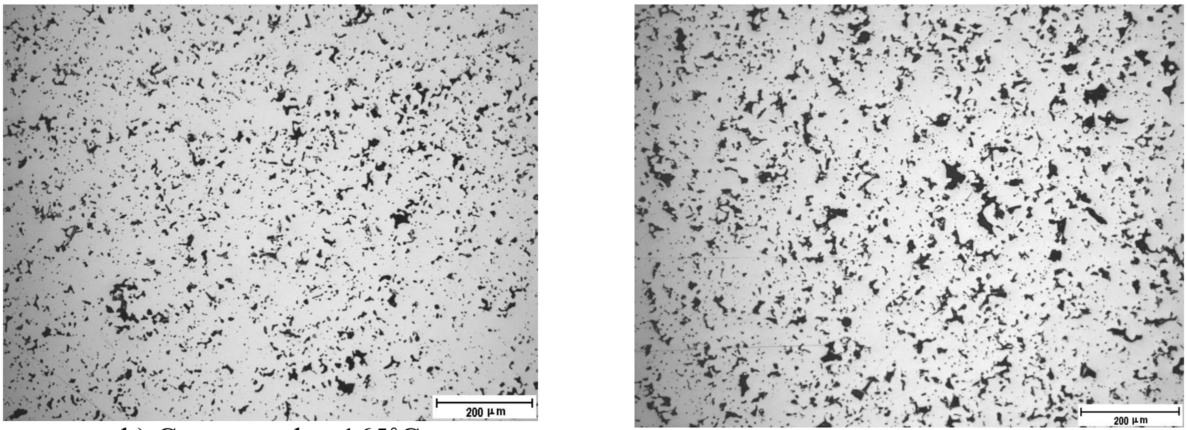
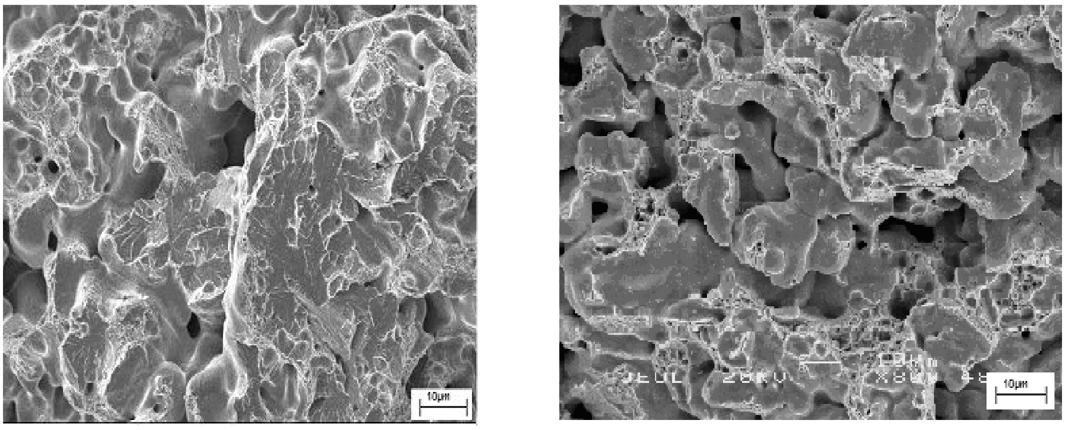


Figure 8. Variation of impact energy samples with compaction temperature



b) Compacted at 165˚C a) Compacted at room temperature

Figure 9. Pore structure of sintered samples compacted at 650MPa



b) Compacted at 165˚C a) Compacted at room temperature

Figure 10. SEM micrograph of sintered samples compacted at 650 MPa

4. Conclusion

The effect of die wall temperature and compaction pressure for warm compaction of Astaloy CrM has been studied. This work can be concluded as follows:

1. With warm compaction densities as high as 96% can be obtained. Increased density can be attributed to increased radial and longitudinal stresses as well as crushing of some powder particles.

2. density of the green compact increases linearly with temperature up to 165oC. At this temperature and compaction pressure of 650 MPa, a density increase of 0.22 cm^3/g in green compacts over room temperature compaction has been observed. The density increase for sintered samples is also linear with increase in compaction temperature, but above this temperature, it slightly falls down.

3. Green strength is improved due to increased fluidity of the lubricant at higher temperature, causing the lubricant to move from the bulk of sample to die walls. Increased meta-to-metal contact can increase green density as much as 40%.

4. Maximum strength of 923 MPa is observed at 150oC and 650 MPa, showing a 10% increase as compared to samples compacted at room temperature. Above this temperature, the strength declines slightly which can be attributed to poor functioning of the lubricant. A 20% increase in impact strength in observed for samples compacted at 150oC and 650 MPa.

5. metallographic examination of unetched samples shows improved morphology of voids with increased compaction temperature. Rounding of pores greatly reduces stress concentrators, thus affecting load bearing capacity of the sample.

6. Fractographs shows increased soft areas (due to increased thickness of necks) and reduced brittle sections. Both these changes improve mechanical properties.

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