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Study on the Doping Effect Cr-doped Fe Metal Powder and Sintering Temperature on Microstructure and Mechanical Properties of Spur Gear Fabricated by Powder Metallurgy

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ABSTRACT

The Spur gear Specimens are fabricated which is vital part of automotive machine by using Cr-doped the Fe metal powder.In order to prepare the specimens, binder is mixed with metal powder and mechanical press for compaction about 20 ton/in^2 followed by non-reactive sintering at 1100°C. Cr doped Fe metal powder was prepared in the form of GC with percentage values of 0, 0.5, 1.0, 1.5, and 2.0%. The Cr element has been successfully distributed into the main ferrite or Fe phase. However, there is a difference when the Cr percentage is 2%, it is possible that saturation will occur which results in the accumulation of Cr powder so that a new phase is formed which gives rise to new granules. We can confirm that there is a certain limit in the addition of the element Cr in the manufacture of gears made from Fe powder. Based on the calculation, the average number of the Vickers micro hardness as a function of Cr content of 0, 0.5, 1, 1.5, and 2% respectively were estimated at about 131, 184, 291, 302 and 270 HV/0.01, respectively. Furthermore, four samples with different sintering temperatures were prepared for comparative purposes. The shrinkage ratio of the GC after sintering at 900, 1000, 1100, and 1200 C was estimated to be 4.3, 5.7, 7.6, and 9.4%, respectively. The shrinkage ratio of the GC increased linearly when the sintering temperature increased. Sintering temperature variations produce differences in the microstructure of each sample. With the increase of the sintering temperatures, the grains will reach a permanent bond because the constituent particles are fully agglomerate. As a result, grain boundaries between particles will decrease causing the dimensions of the product to shrink so that its density increases. Theoretically, the density value is inversely proportional to porosity. The higher the density value of a product, the lower the porosity value. An increasing the sintering temperature could lead to the appearance of a liquid and the healing of pores. The hardness value and the shrinkage ratio increased with the sintering temperature increased from 900 to 1200°C. The hardness value increased from 297 to 305 HV/0.01, as the sintering temperature increased from 900 to 1200°C.

Key Words: Spur Gear, Cr-doped, Sintering, Microstructure, Hardness.

1. INTRODUCTION

Gear is one of the mechanical parts that engineer frequently used. The gears are used to transmit power from one part of an engine to another. There are many types of gears, straight-cut gear or spur gear is the simplest type of gear and it's commonly used. The predominant market for press and sinter structural metal powder parts is the automotive sector. On average across all geographical regions, around 80% of all Powder Metallurgy structural components are for automotive applications. Around 75% of these automotive applications are components for transmissions (automatic and manual) and for engines [1]. Complex shape can be produced is one of the advantages of powder metallurgy, such as gears, cams, and etc. Powder metallurgy is often possible to produce the parts that cannot be economically machined or casting [2].

Sintering is one of the important process in the powder metallurgy. The green compact was carried out at temperatures between 0.7 up to 0.9 of the metal's melting point (absolute scale). The term of solid-phase sintering are sometimes used for the conventional sintering because the metal remains un-melted at these treatment temperatures [3]. The powder metallurgy process generally consists of four basic steps: (1) powder manufacture, (2) mixing or blending, (3) compacting, and (4) sintering. Compaction is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at

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atmospheric pressure [2]. Grupp et.al reported that sintering of single phase powders into porous compact can be conducted under conditions that allow largely preserving the initial particle morphology [4]. The microstructure of the particles of the reaction might be different from that of the initial powders for the case of reactive sintering [5].

Figure 1 shows the flow chart of the fundamental powder metallurgy steps. About eighty percent of all metallurgy powder is fabricted by some shape of melt atomization, where the liquid material is disintegrated into small droplets that cool and solidify into particles [2]. Many studies already performed to make the spur gear by powder metallurgy process. Yafie et.al [6] reported that 900°C is the best sintering temperature with the hardness value was 34,7 HRb for 2 h holding time sintering temperature. Alauzi et.al [7] also reported spurs gear has been successfully made using copper and aluminum powder. The green compact was compacted and sinter at 868 C. The best results were obtained with a composition of 75% copper and 25% aluminum. However, the hardness results obtained have not reached the desired value. X. Lie et.al [8] reported the results of the manufacture of gears using the powder metallurgy process. Ni, C, and Mo were doped into the iron me°°tal powder which is the main powder. The green compact was sinter at 1120°C for 45 minutes holding time sintering temperature. The result showed that Young's modulus values were lower than the conventional process. Based on the powder metallurgy process and previous research, this work simply focused to produce green compact without produce the metal powders. To the best of our knowledge, the Chromium (Cr) doped into commercial Fe (Ferrous) metal powder to prepare green compact material was not studied before. In this research, we focus on fabricating the feasibility of Cr doped Fe powder with variation sintering temperature in order to optimize the spur gear and investigated the mechanical property.

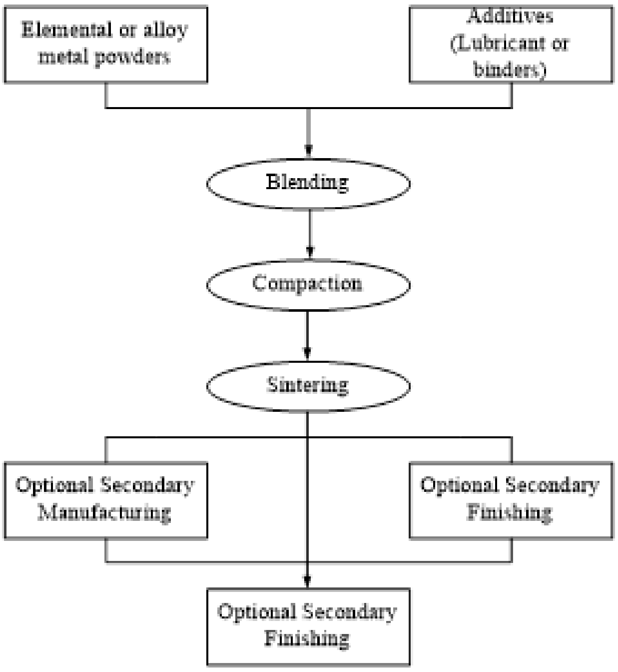

Figure 1. Flow chart of the fundamental powder metallurgy steps.

2. EXPERIMENTAL PROCEDURE

The commercial Fe and Cr metal powder supplied by Farco Chemical Supplies with a particle size of about 100 mesh has been used to fabricate the green compact (GC). Cr doped Fe metal powder was prepared in the form of GC with percentage values of 0, 0.5, 1.0, 1.5, and 2.0%. These constituent powders were blended by the conventional process for 12 h. Water is used in order to reduce dust formation and enhance particle mobility (Fig. 2). Cold compaction was used with uniaxial pressure and the working pressure was remained at 20 ton/in^2. The pressed samples were sintered under atmosphere via a two-step non-reactive sintering (pre heating) technique at 1100 C for 1 hour with a holding at 600 ^{o}C for 30 min (Fig. 3). The microstructures of the samples were characterized by using SEM-EDS and an optical microscope (Nikon Eclipse E600 Fluorescence Microscope). The ZHV Micro Vickers hardness tester was used for microhardness measurements (HM- 122 Mitutoyo). The averages of hardness tests of the samples were taken and compared from at least ten different areas. The shrinkage ratio of the sample thickness after sintering was calculated using the theoretical equation (1).

$$S_r = \frac{T_B - T_A}{T_B} x100\% \qquad (1)$$

Where T_b is the thickness of the sample before sintering and T_a is the thickness of the sample after sintering.

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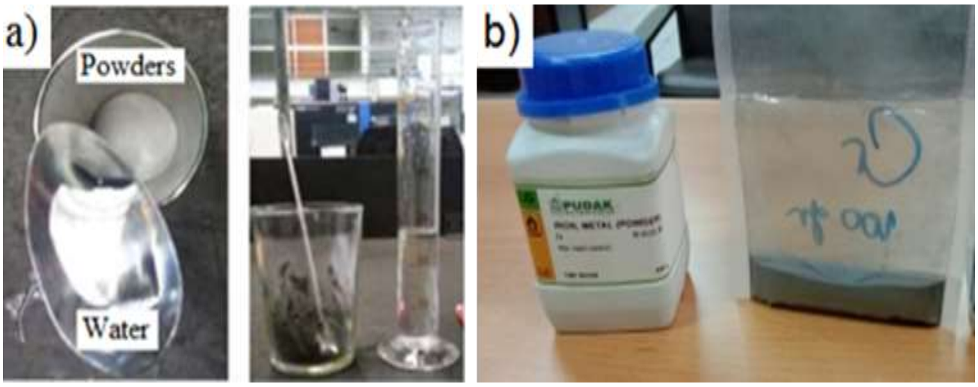

Fig 2. a) Sample preparations, and b) The commercial Fe and Cr metal powder.

3. RESULTS AND DISCUSSION

3.1 Effect of Cr content variation on properties Cr-doped Fe Spur Gear Metal Powder

Figure 4 shows the metallographic results of samples as a function of Cr content of 0, 0.5, 1, 1.5, and 2%. Figure 5 show SEM surface image of 2%Cr-doped Fe sample after the metallographic process. As can be seen clearly in Figures 10 and 11 on the microstructure images, it can be seen that the formed phase is relatively uniform in the ferrite matrix. The SEM-EDS results in Figure 4 prove that the Cr element has been successfully distributed into the main ferrite or Fe phase. However, there is a difference when the Cr percentage is 2%, it is possible that saturation will occur which results in the accumulation of Cr powder so that a new phase is formed which gives rise to new granules. We can confirm that there is a certain limit in the addition of the element Cr in the manufacture of gears made from Fe powder.

Fig 3. a), b) The mechanical press for the compacting of metal powders and the set of the compaction tooling of the dies, and c), d) Heating furnace for the sintering process.

The hardness test was carried based on ASTM E384-17 micro Vickers hardness testing standards. The determination of the test points on the sample (in Fig 6) is carried out in the transverse direction according to AGMA 925-B03 standards. There are many factors must be considered for mechanical properties. Compaction pressure, particle size, and size distribution, alloy composition, heating rates, sintering temperatures, and time [9]. Figure 6.f show the surface image of indenter tracer of the Vickers microhardness test and figure 7 shows the results of the Vickres hardness test at 5 test points. Based on the calculation, the average number of the Vickers micro hardness as a function of Cr content of 0, 0.5, 1, 1.5, and 2% respectively were estimated at about 131, 184, 291, 302 and 270 HV/0.01, respectively. An interesting hardness was observed, the value of hardness was increased with increasing doping content. The hardness value increased from 131 to 302 HV/0.01, as the doping Cr increased from 0 to 1.5%.

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Fig 4. The Metallographic results of samples as a function of Cr content of 0, 0.5, 1, 1.5, and 2% respectively from the left to the right.

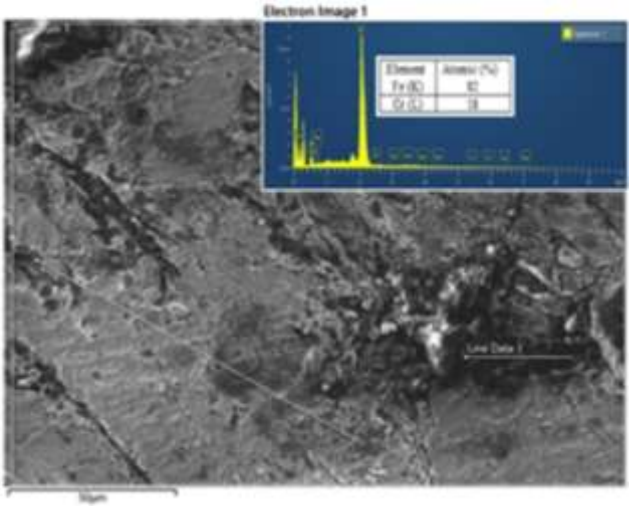

Fig. 5 SEM surface image of 2%Cr-doped Fe sample after the metallographic process.

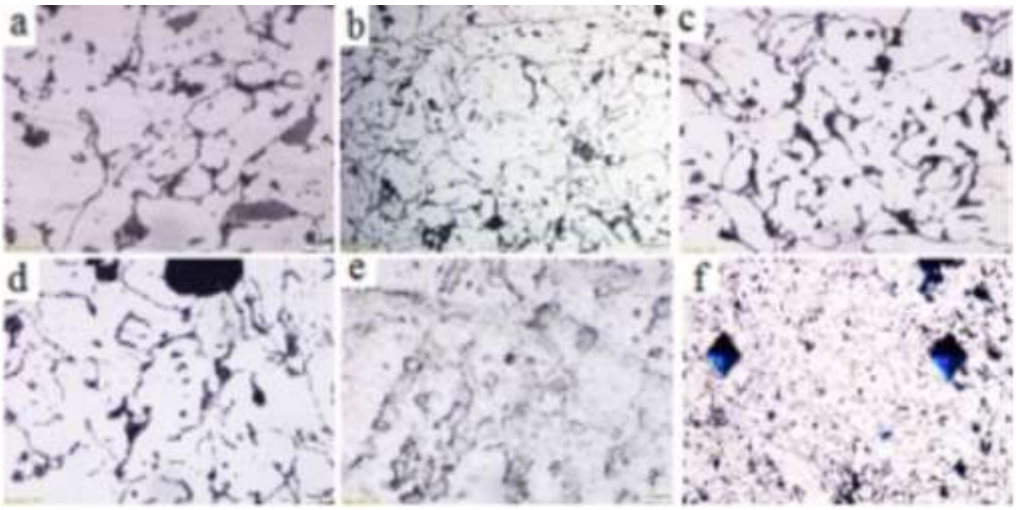

Fig 6. Microstructure images of samples on different percentage of doping Cr. a) 0, b) 0.5, c) 1.0, d) 1.5, e) 2.0%, and f) Vickers hardness indenter trace for 1.5%Cr-doped Fe.

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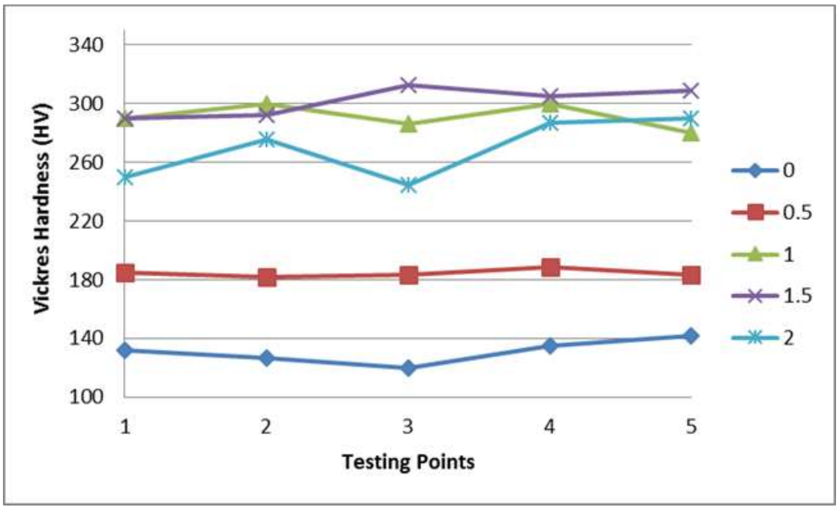

Fig 7. The behavior of the Vickers hardness value of the samples with the different percentages of doping Cr on five testing points.

3.2 Effect of variation temperature on properties 1.5%Cr-doped Fe Spur Gear Metal Powder

Table 1. Data measurement of 1.5%Cr-doped Fe after sintering at 900, 1000, 1100, and 1200°C.

The ratio of shrinkage	**Sintering Temperatures (C)**			
	900	**1000**	**1100**	**1200**
T_B (mm)	6.30	6.28	6.32	6.30
T_A (mm)	6.03	5.92	5.84	5.71

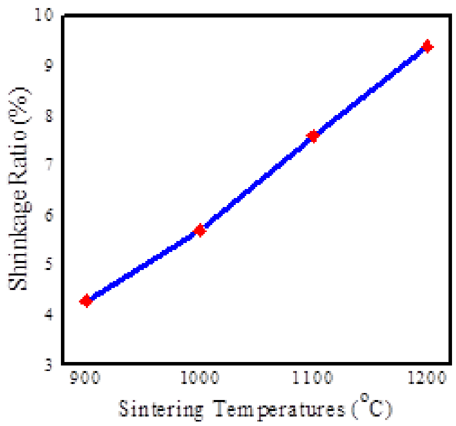

Fig. 8 The shrinkage ratio of the green compact 1.5%Cr-doped Fe sintered at 900-1200^0 C.

Table 1 shows the measurement data of the ratio of shrinkage after sintering at 900, 1000, 1100, and 1200°C, respectively. Based on the Eq.1, the shrinkage ratio of the GC after sintering at 900, 1000, 1100, and 1200°C was estimated to be 4.3, 5.7, 7.6, and 9.4%, respectively (Fig. 8). Figure 9 shows the microstructure images of gears after sintering at 900, 1000, 1100, and 1200°C, respectively. As indicated clearly in Fig 8, the shrinkage ratio of the GC increased linearly when the sintering temperature increased. Sintering temperature variations produce differences in the microstructure of each sample. With the increase of the sintering temperatures, the grains will reach a permanent bond because the constituent particles are fully agglomerate. As a result, grain boundaries between particles will decrease causing the dimensions of the product to shrink so that its density increases. Theoretically, the density value is inversely proportional to porosity. The higher the density value of a product, the lower the porosity value. An increasing the sintering temperature could lead to the appearance of a liquid and the healing of pores [10].

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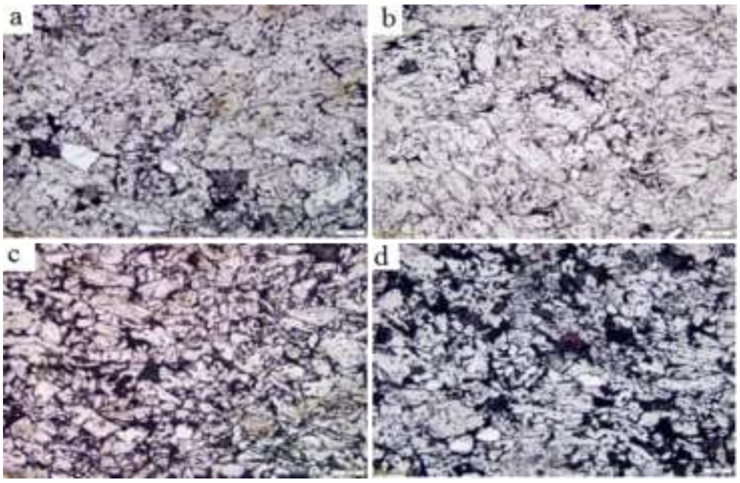

Fig 9. Microstructure images of gears after sintering at a) 900°C, b) 1000°C, c) 1100°C, and d) 1200°C.

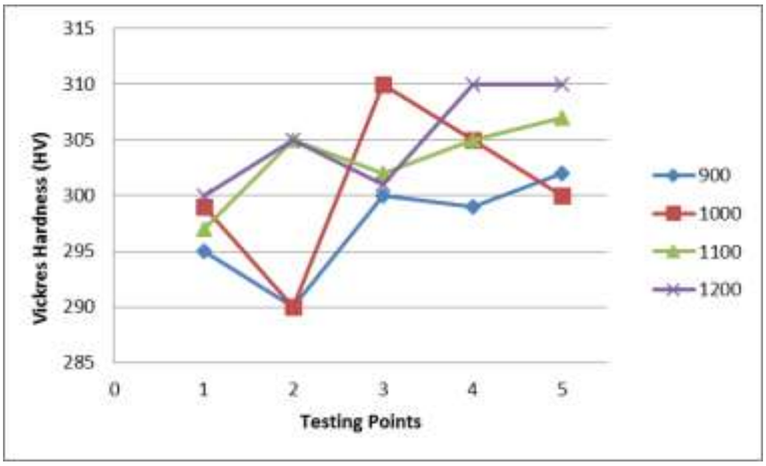

Fig. 10 Behaviour of the hardness of the samples with the variation sintering temperatures on five testing points.

The hardness test was carried based on ASTM E384-17 micro Vickers hardness testing standards. The determination of the test points on the sample (in Fig 10) is carried out in the transverse direction according to AGMA 925-B03 standards. There are many factors must be considered for mechanical properties. Compaction pressure, particle size, and size distribution, alloy composition, heating rates, sintering temperatures, and time [9]. Based on the calculation, the average number of the Vickers micro hardness after sintering at 900, 1000, 1100, and 1200°C was estimated at about 297, 300, 303, and 305 HV/0.01, respectively. An interesting hardness was observed, the value of hardness was increased with increasing sintering temperatures. The hardness value increased from 297 to 305 HV/0.01, as the sintering temperature increased from 900 to 1200°C.

4. CONCLUSION

The spur gear was successfully fabricated by Cr-doped Fe metal powder. Cr doped Fe metal powder was prepared in the form of GC with percentage values of 0, 0.5, 1.0, 1.5, and 2.0%. Water is used as a binder and continued compaction about 20 ton/in^2 followed by non-reactive sintering at 1100 C. The Cr element has been successfully distributed into the main ferrite or Fe phase. However, there is a difference when the Cr percentage is 2%, it is possible that saturation will occur which results in the accumulation of Cr powder so that a new phase is formed which gives rise to new granules. We can confirm that there is a certain limit in the addition of the element Cr in the manufacture of gears made from Fe powder. Based on the calculation, the average number of the Vickers micro hardness as a function of Cr content of 0, 0.5, 1, 1.5, and 2% respectively were estimated at about 131, 184, 291, 302 and 270 HV/0.01, respectively.

Furthermore, there are four samples with 900, 1000, 1100 and 1200°C sintering temperatures were prepared for differentiative objectives. The shrinkage ratio of the GC after sintering at 900, 1000, 1100, and 1200°C were estimated to be 4.3, 5.7, 7.6, and 9.4%, respectively. The shrinkage ratio of the GC increased linearly when the sintering temperature increased. Sintering temperature variations produce differences in the microstructure of each sample. With the increase of the sintering temperatures, the grains will reach a permanent bond because the constituent particles are fully agglomerate. As a result, grain boundaries between particles will decrease causing the dimensions of the product to shrink so that its density increases. Theoretically, the density value is inversely proportional to porosity. The higher the density value of a product, the lower the porosity value. An

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