Investigation of influences of alloying elements and sintering temperature on the properties of high strength low alloyed sintered steel

M. Azadbeh[1], N. Peyghambardoust[2], VM. Mohammadpour[3]* and A. Kalantari[4]
Department of Materials Engineering, Sahand University of Technology, Tabriz, Iran,P.O.Box 51335-1996

Abstract
Producing parts with high density and improved mechanical properties is one of the most important aims of powder metallurgy process. There are many factors for attaining modified properties in sintered parts but among them controlling type and quantity of alloying elements and manufacturing parameters such as compacting pressure, sintering temperature are the most effective.

In this research, two series of Cr-Mo prealloyed powders with 1.5% and 3% chromium contents were used, and then influences of manufacturing parameters on physical and mechanical properties were investigated. The results show that by compacting pressure and sintering temperature increment and chromium content decrement, density is increased and subsequently physical and mechanical properties of low alloyed sintered steels are improved.

Keywords: Low alloyed sintered steel, sintering temperature, density, electrical-conductivity, mechanical properties.

1. Introduction
In recent years, demands for the production of powder metallurgy (PM) steel parts that are subjected to high mechanical loads have increased owing to cost efficiency and dimensional accuracy of this method. Several methods are under development to increase the load bearing capacity of sintered ferrous materials. The major trends of these methods are the alloy development or modification of manufacturing process [1)].

By using prealloyed powders as a raw material, P/M parts with higher performance level are obtainable. The most common alloying elements used in PM market are nickel (Ni) and molybdenum (Mo). This is because mentioned alloying elements are not sensitive to oxidation during sintering process [2)]. Chromium is interesting as a prealloying element due to its performance enhancing ability and relatively low cost [3)]. Chromium alloyed sintered steels offer considerable potentials with regard to mechanical properties both in the as-sintered and as- heat treated states. In general, Chromium alloyed sintered steels offer a considerable potential with regard to mechanical properties [4)]. Chromium was not used in the past as well as other alloying elements due to its high affinity for oxygen. Consequently, by developing a new generation of prealloyed powders in combination with the Nitrogen-Hydrogen atmospheres and furnaces which have been available in recent years, the advantages of chromium can be fully exploited [5)]. All in all, high strength P/M parts with accurate dimensions can be produced by using chromium prealloyed powders combined with appropriate manufacturing processes such as pressing pressure and sintering temperature [6)].

In this investigation, the aim was to assess the effect of manufacturing parameters and alloying elements contents on the physical and mechanical properties of FL-5208 and FL-5305.

2. Experimental procedure
Prealloyed powders FL-5208 (Fe-1.5 wt.% Cr-0.2 wt.% Mo) and FL-5305 (Fe- 3 wt.% Cr-0.5 wt.% Mo) were mixed with 0.6 wt.% C (natural graphite UF4), and the mixtures were uniaxially compacted at different compacting pressures (500, 600, 700 MPa) to bars with rectangular shape (55×10×10 mm) in a pressing tool with a floating die. To prevent the sticking of the samples together, they were put in steel boxes filled with alumina powder. Delubing of these samples was accomplished in a small laboratory furnace at 600°C for 30 minutes. Samples were sintered at three different temperatures (1120, 1250 and 1300°C) for 60 minutes in a laboratory furnace in flowing high purity nitrogen (99.999 purity, flow rate 2 lit/min).

Densities of green compacts were determined from measurements of the mass and the dimensions of the compacts, while those of the sintered compacts were determined using Archimedes principle (DIN ISO 3369). The electrical-resistivity of sintered samples was measured according to ASTM D4496. The transverse rupture strength was determined according to ASTM B528, the distance between supports being 25.4 mm using a Zwick 1474 universal testing machine.

* Corresponding author:
Tel: +98 (914) 1901654, Fax: +98 (412) 3459452
E-mail: v_mohammadpour@sut.ac.ir
Address: Sahand University of Technology, Tabriz, Iran, P.O. Box 51335-1996.
1.PhD
2,3. M.Sc. Student
4. M.Sc.

Determination of the impact energy was carried out using a Wolpert pendulum at room temperature on 55×10×10 mm specimens (by averaging the results of four parallel tests). The adopted available energy was 50 J and the impact velocity was 2.25 m/s. Unnotched specimens were used as given in DIN ISO 5754. The apparent hardness was measured on an EMCO M4U-025 tester with a load of 30 Kgf from carefully sectioned and polished specimen. Metallographic sections were prepared following standard procedures; etching was undertaken with a solution containing 60/40 mix of 1% Nital and 4% Picral. Sintered microstructure was investigated by optical microscopy. In order to obtain information on the deformation and fracture mechanisms, the fracture surfaces were observed in a scanning electron microscope JEOL 6400 in a secondary electron mode.

3. Results and discussion

Obtained Physical and mechanical properties as a result of the experiments are shown graphically in Figs.1-6. Data are mean values of the measurements performed on four samples each.

Fig. 1 clearly shows the lower compressibility of FL-5305 samples toward FL-5208 ones. Less compressibility of higher chromium content samples is due to the creation of solid solution [7].

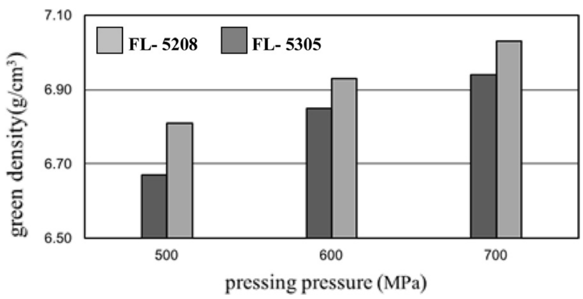

Fig. 1. Green density as a function of compacting pressure for FL-5208 and FL-5305.

According to Fig. 2, sintered density of FL-5208 samples under various manufacturing parameters (compacting pressure) is higher than FL-5305 ones. This is because the sintered density is influenced by green density itself.

As shown in Fig. 3, by increasing the sintered density of specimens, relatively linear decrement in electrical resistivity is obvious. In addition, electrical- resistivity of sintered FL-5305 samples is higher than that of FL-5208 ones at each sintered density. Referring to the work of Danninger et al. [8] and other researchers [9,10], the dependence of electrical resistivity on composition is evident, too.

The results of macro-hardness measurement with a load of 30 kgf (HV 30) in various sintered densities for both samples are depicted in Fig. 4. With an increase in sintered density, the hardness is increased.

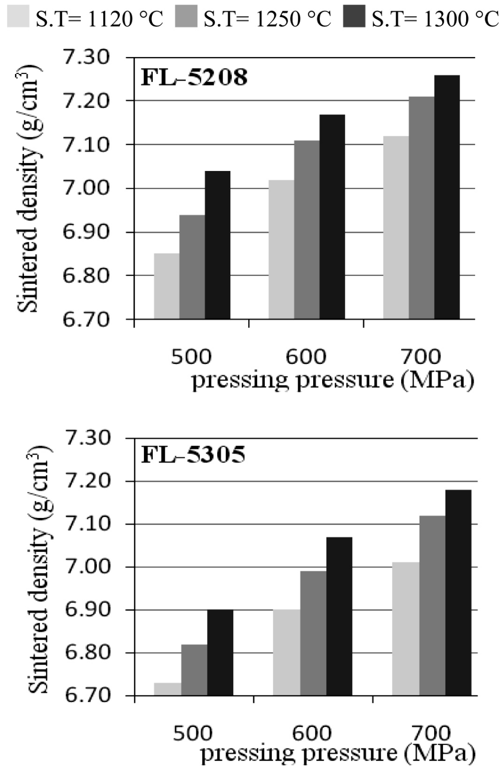

Fig. 2. Effect of compacting pressure and sintering temperature on density (obtained by Archimedes method) for FL-5208 and FL-5305.

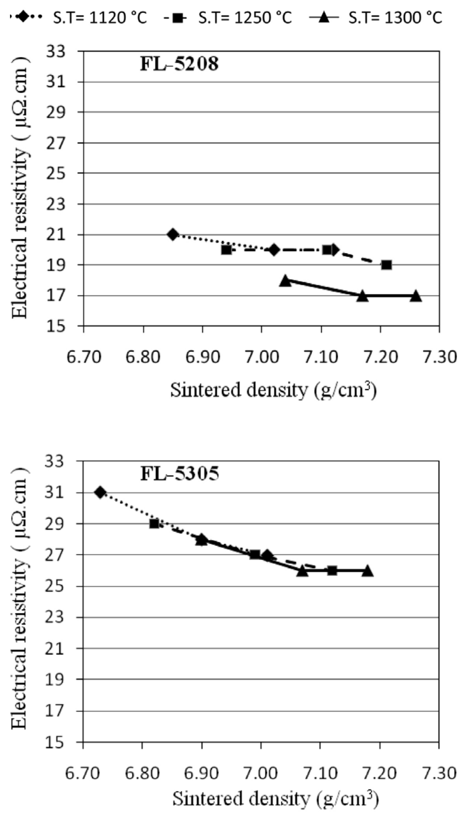

Fig. 3. Electrical resistivity vs. sintered density of FL-5208 and FL-5305.

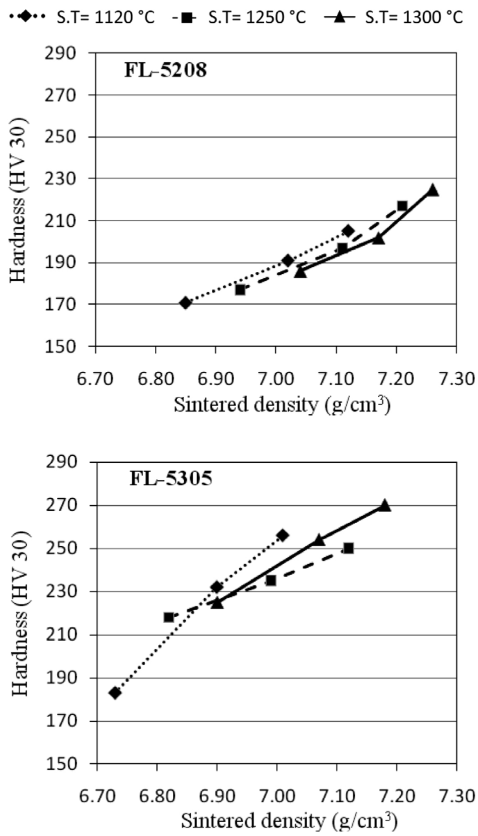

Fig. 4. Hardness of FL-5208 and FL-5305 as a function of sintered density.

On the other hand, the samples with higher chromium content (FL-5305) show higher levels of apparent hardness with respect to those which contain lower alloying elements. Extra carbide creation due to presence of higher amount of chromium in FL-5305 alloy and also increased appearance of second phase such as pearlite- bainite lead to matrix strengthening thus obtaining a higher level of hardness in the mentioned alloy.

Metallographic investigation was performed for revealing the correlation between microstructure and physical/mechanical properties of samples. As shown in Fig. 5, FL-5208 and FL-5305 samples possess ferritic- pearlitic and ferritic- bainitic microstructures, respectively. Evidently, presence of bainitic microstructure in FL-5305 specimens will cause a higher level of hardness in such parts.

According to Fig. 6, usage of 1120°C as sintering temperature lead to a slight increment with an increase in the level of sintered density. Whereas by using higher sintering temperature i.e. 1250 and 1300 °C, mentioned parameter has shown a considerable increase with an increase in the sintered density compared to the lower one. In general, FL-5305 sintered samples show a higher level of impact energy than FL-5208 ones in a distinct sintered density. By comparing the amount of impact energy for both materials, it is concluded that low sintering temperature equal to 1120°C is not a conducive choice for mentioned alloys.

Increase in impact energy at high sintering temperatures could refer to obvious roundness of pores at such temperatures which cause a significant increase in stress concentration at inter-particle bonding.

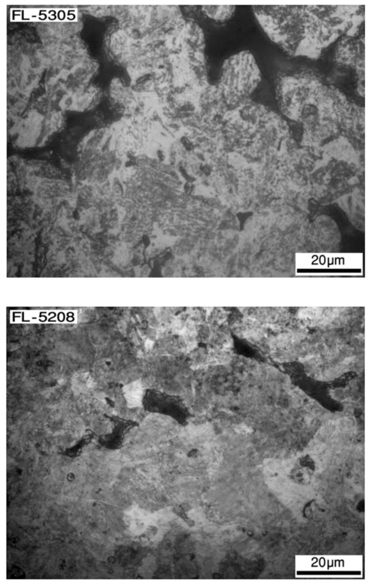

Fig. 5. Typical microstructure of sintered FL-5208 and FL-5305;These samples were compacted at 700 MPa and sintered at 1120°C for 60 min.

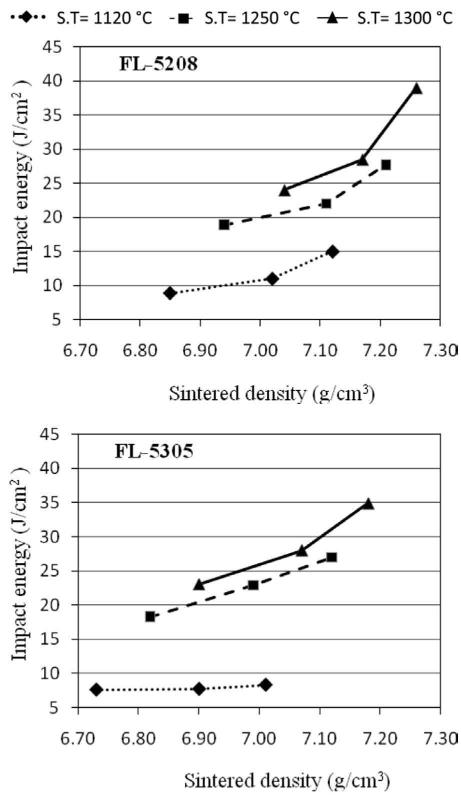

Fig. 6. Correlation between impact energy and sintered density for FL-5208 and FL-5305.

Fig. 7 shows that the transverse rupture strength of sintered samples at 1250 °C increased with linear coefficient of 0.97 and 0.99 for FL-5208 and FL-5305 samples, respectively, with regard to an increase in sintered density. Transverse rupture strength level of FL-5305 samples is more than FL-5208 ones at each sintered density. This is because of extra content of chromium which causes the presence of more secondary hard phases such as carbide at the matrix of FL-5305. These hard phases lead to matrix strengthening and naturally interparticle bonding strengthening. Thus, the level of transverse rupture strength of FL-5305 is increased.

As shown in Fig. 8, at lower sintering temperatures the formation of retarded contacts between particles were dominant. This could be related to the oxide layers which were reduced only at higher sintering temperatures [11-13]. By increasing sintering temperatures, pores were rounded and open porosities were reduced. These effects caused a significant increment in load bearing cross-section (Ac) and therefore improvement in hardness and transverse rupture strength of Cr-Mo low alloyed sintered steels. Indeed, the improvement of mechanical properties with an increase in sintering temperature is mainly caused by better deoxidation of the surface oxides which enhances the formation and growing of sintering contacts [14].

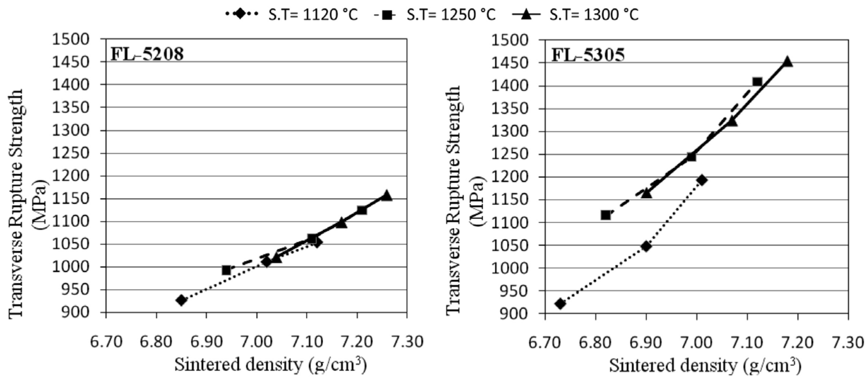

Fig. 7. Influence of sintered density on transverse rupture strength of FL-5208 and FL-5305 steels.

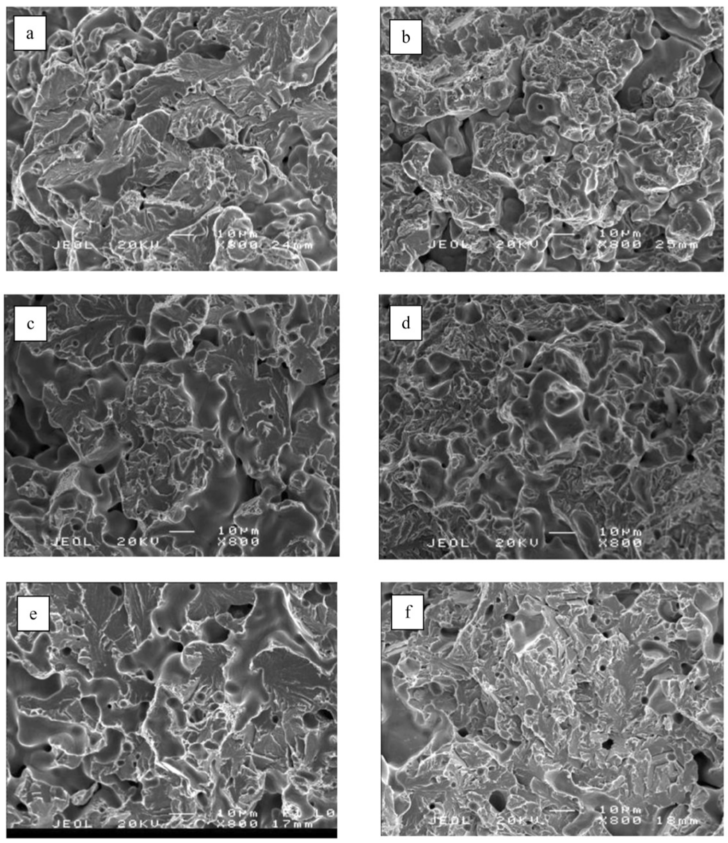

Fig. 8. Fracture surfaces of sintered samples ; (a) FL-5208 sintered at 1120 °C, (b) FL-5305 sintered at 1120 °C, (c) FL-5208 sintered at 1250 °C, (d) FL-5305 sintered at 1250 °C, (e) FL-5208 sintered at 1300 °C and (f) FL-5305 sintered at 1300 °C (Impact test specimen – broken after immersion in liquid Nitrogen).

4. Conclusion

- In general, sintered steels with higher chromium content show improved mechanical properties compared to those with lower chromium content.
- There is a distinct correlation between sintered density, mechanical properties and electrical resistivity of low alloyed sintered steels. By decreasing the porosity level, load bearing cross section and mechanical properties of sintered samples such as hardness, impact energy and transverse rupture strength are increased and on the contrary, electrical resistivity is decreased. Regarding these findings, reversely, we can use electrical resistivity as a non-destructive parameter in predicting sintered density and consequently the mechanical properties of low alloyed sintered steel parts.
- To sum up, there are two significant concerns with the usage of FL-5305 prealloyed powder. Its low compressibility in addition to high affinity of Cr toward Oxygen. Regarding these weak points, sintering of such specimens may encounter some difficulties. If all of these concerns and also obtained properties from FL-5208 prealloyed powder through this investigation are contemplated, the it is concluded that FL-5208 accompanying the appropriate manufacturing parameters would be a substitute for FL-5305.

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