DIMENSIONAL CONTROL USING CHROMIUM ALLOYED MATERIALS VERSUS CONVENTIONAL P/M ALLOYED MATERIALS

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ABSTRACT

Powder metallurgy components are expected not only to have good mechanical properties but also to meet dimensional tolerances consistently. Chromium pre-alloyed materials have received great interest recently due to properties achievable, sinter hardening response and possibility in improving dimensional tolerances. An additional advantage of using chromium as an alloying element is its low cost when compared to other alloying elements. In this study, sintering production tests have been performed in order to evaluate dimensional capability using Cr-alloyed materials verses conventional P/M alloyed materials. The first part of the study compares the Cr-alloyed materials with Fe-Cu-C alloyed materials under conventional sintering conditions. The second part of the study compares the Cr-alloyed materials against traditional Ni/Mo alloyed materials under sinter hardening conditions.

INTRODUCTION

High performance P/M components that require structural integrity in demanding applications can be achieved by increasing density, strengthening and homogenizing material structure by using alloying elements, and sinter hardening. As alloying elements, chromium and molybdenum have more advantages in hardening the structure of materials than nickel and copper (1). The drawback of using chromium is its high-oxygen affinity, but this limitation on alloying can be minimized by using prealloyed powder and improving sintering furnace conditions. Recent advances in sintering technology, especially in furnace equipment make it possible for the sintering of chromium-containing materials (2). Therefore, chromium pre-alloyed materials have received great interest recently due to the properties achievable, sinter hardening response and possibility in improving dimensional tolerances.

The biggest advantage of P/M technology is to make large volumes of parts with very close dimensional tolerances and minimized machining operations. Therefore, control of the dimensional change is an important parameter required to produce competitive P/M components. The dimensional tolerance of P/M parts is determined by material composition, compacting density and sintering conditions. It is well known that carbon and copper are two major elements that cause significant dimensional change during sintering operations. Segregation in carbon or copper greatly affects not only the reproducibility of part dimensions but also the dimensional tolerance.

Therefore, minimizing the addition of carbon and copper can offer an alternative for dimensional control of P/M material. As newly developed water atomized prealloyed steel powder with 1.5%Cr and 0.2%Mo, Astaloy CrL is able to achieve comparable mechanical properties to conventional P/M alloyed materials

containing less alloying elements and using less carbon (3). Therefore it is possible to improve dimensional tolerance using the Cr-alloyed material that contains minimized carbon and copper additions.

In this paper, the dimensional capability using Cr-alloyed materials such as Astaloy CrL verses conventional P/M alloyed materials was evaluated upon actual P/M gears. Two sintering conditions were used for the comparison studies: 1) conventional sintering conditions to compare with Fe-Cu steel and 2) sinter hardening conditions to compare with Ni/Mo/Cu alloyed steel.

EXPERIMENTAL PROCEDURES

Three grades of commercial plain and prealloyed powders from North American Höganäs, USA were used as base iron for this study. The base iron powders were mixed with required amount of copper (Cu-165 grade from ACu Powder), natural graphite (SW-1651 grade from Asbury Graphite) and lubricant (Kenolobe P11 grade from North American Höganäs) to make premix powders. The chemical composition of each premix is shown in Table 1.

Table 1 Chemical Compositions of Premixes

Sintering	Material Definition	Base iron	Chemical Composition, %wt					
			Cr*	Mo*	Ni*	Cu	Graphite	Lubricant
Conventional	CrL+0.5C	Astaloy CrL	1.5	0.2			0.5	0.6
	FC-0208	ASC100.29				2.0	0.8	0.6
Sinter-hardening	CrL+Cu+C	Astaloy CrL	1.5	0.2		1.0	0.75	0.6
	FLC-4608	Astaloy A		0.55	1.9	2.0	0.75	0.6

* prealloyed in iron powder



Figure 1 Sample of P/M spur gear

The premixes were compacted into ϕ2 inches (ϕ 50.8 mm) diameter spur gears with a green density of 7.0 g/cm^3 (see Figure 1) using a 200 ton hydraulic press. The gears were then sintered in a 24 inch (610 mm) steel-mesh belt furnace at 2050°F (1120°C) for 30 min. in an atmosphere of 95% nitrogen and 5% hydrogen. Sinter hardening conditions were achieved by using a rapid cooling system (about 3~5°F/s or 2~3°C/s of cooling rate) on the same furnace used for conventional sintering.

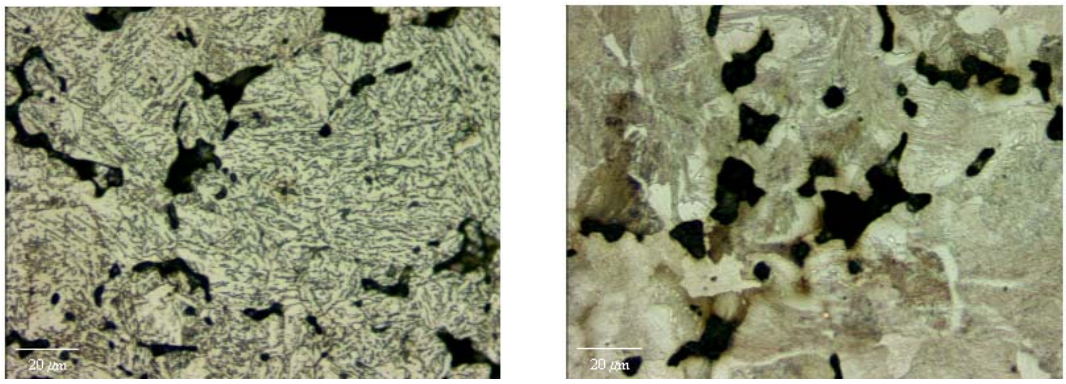
All gears were numbered and their OD and ID dimensions were measured prior to sintering. After the sintering, sintered properties of the gears were evaluated including density, apparent hardness and microhardness, combined carbon content, microstructure, gear tooth porosity, and dimensional changes in OD and ID dimensions. For dimension measurement, the OD was measured at two locations (0° and 90°) with a digital Quick Micrometer (Mitutoyo, Japan) and the ID was measured with a digital internal micrometer (Starrett, USA).

RESULTS AND DISCUSSIONS

(1) Conventional Sintering

Microstructure and sintered properties

The microstructures of CrL+0.5C and FC-0208 materials obtained under conventional sintering conditions are shown in Figure 2. As compared to Fe-Cu alloyed materials that consist of entirely pearlite phase, the CrL material has bainitic structure (upper bainite).



CrL+0.5C (Astaloy CrL+0.46%C) FC-0208 (Fe+2%Cu+0.74%C)

Figure 2 Microstructures of CrL+0.5C and FC-0208 materials sintered under conventional sintering [2050°F (1120°C)@30min, 95/5 N_2/H_2]

Even though the CrL material had much lower combined carbon content than the FC-0208, it still has equivalent apparent hardness and microhardness [see Table 2]. Figure 3 shows the mechanical property studies on Cr-alloyed materials verses Fe-Cu materials (3). It can be seen that the CrL material has equal or higher tensile strength (UTS) and yield strength (YS) than Fe-Cu alloyed materials but it needs much less combined carbon content and no copper addition.

Table 2 Hardness comparison between CrL+0.5C and FC-0208 materials [2050°F (1120°C)@30min, 95/5 N_2/H_2]

Material	Conventional Sintering	
	CrL+0.5C	FC-0208
Sintered density, g/cm^3	7.01	6.92
Carbon content, %	0.46	0.74
Apparent hardness, HRB	82	80
Microhardness, $Hv\text{-}_{0.1\ kg}$	258	238

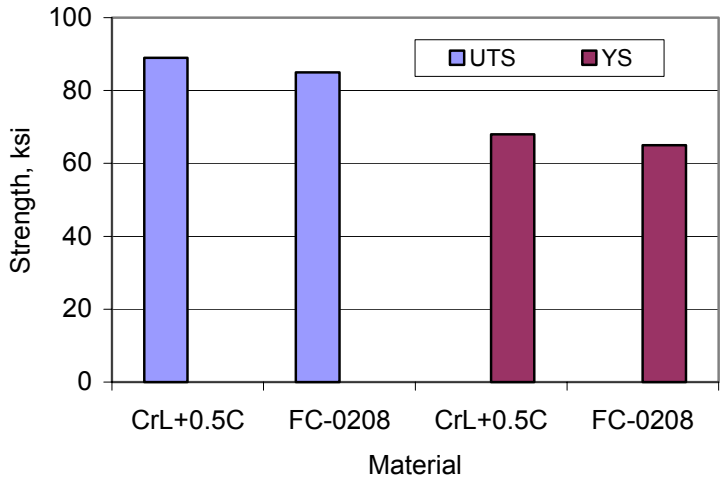


Figure 3 Mechanical properties of CrL+0.5C and FC-0208 materials compacted at 7.0 g/cm^3 with conventional sintering [2050°F (1120°C)@30min, 95/5 N_2/H_2]

After sintering, the sintered density of CrL+0.5C material was almost the same as its green density while the Fe-Cu material (FC-0208) has lower sintered density than its green density due to the presence of copper that causes more expansion. Figure 4 shows the cross-section of gear tooth of the evaluated materials. As compared to FC-0208 material, the CrL+0.5C material has much smaller and more homogeneous pores in its structure. The large pores created in FC-0208 material are the prior copper locations. There is no copper used in the CrL+0.5C material and thus no residual pores were formed. It is well known that the porosity in materials has a large impact on mechanical properties of P/M components. Therefore, the CrL material offers great advantages in enhancing mechanical properties as compared to the traditional Fe-Cu material.

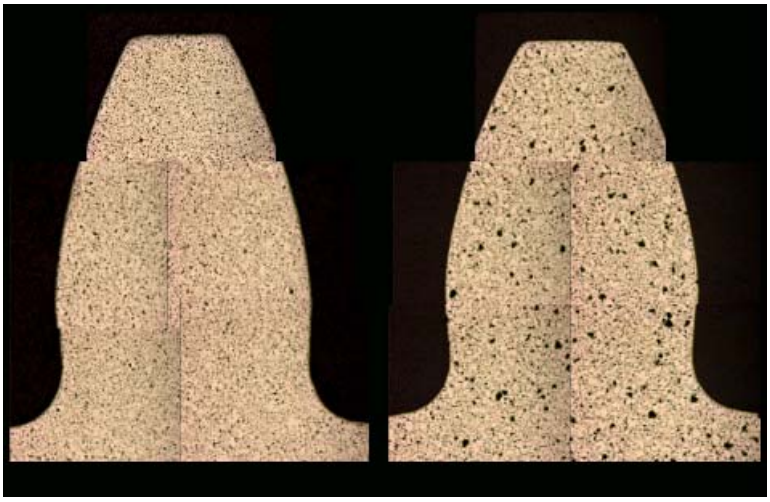


Figure 4 Cross-section of gear teeth of CrL+0.5C and FC-0208 materials.

Dimensional tolerance

With using much less carbon and no copper addition, as shown in Figure 3, the CrL+0.5C material presents equivalent mechanical properties as compared to FC-0208 that is widely used for structural P/M parts. Since carbon and copper are two major elements that cause significant dimensional change during sintering operations, segregation in carbon or copper greatly affects not only on the reproducibility of part dimensions but also on the dimensional tolerance. Therefore, minimizing the addition of carbon and copper can offer an alternative for dimensional control of P/M material. It may be possible to improve dimensional tolerances by using the Cr-alloyed material.

Figure 5 shows the average dimensional change of the gears using CrL+0.5C and FC-0208 materials after conventional sintering. As expected, the FC-0208 material gives dimensional change about twice larger than the CrL material, regardless in OD and ID dimensions. The copper and carbon in FC-0208 causes the expansions.

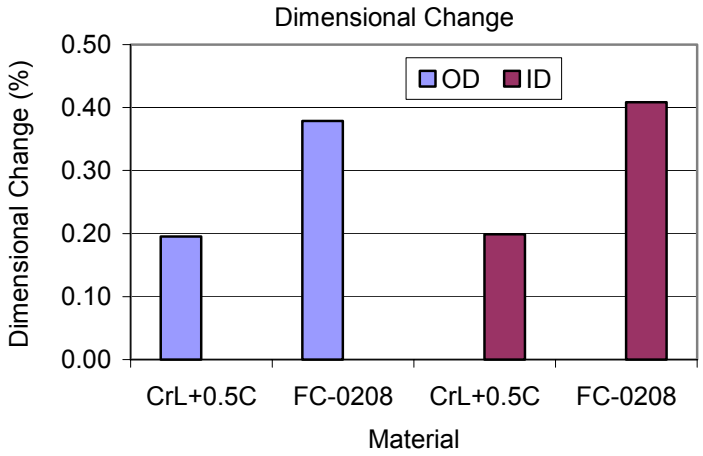


Figure 5 Average dimensional changes in OD and ID of gears using CrL+0.5C and FC-0208 materials sintered under conventional sintering [2050°F(1120°C)@30min, 95/5 N_2/H_2]

Figure 6 shows the variations in dimensions of gears using these two materials and Figure 7 shows the standard deviation of gear dimensions. For the reproducibility of dimensions and stability of dimensional change, the CrL-A material is comparable to the FC-0208 material in ID dimension but it has much better reproducibility of dimensions and stability of dimensional change in OD dimension than the FC-0208 material.

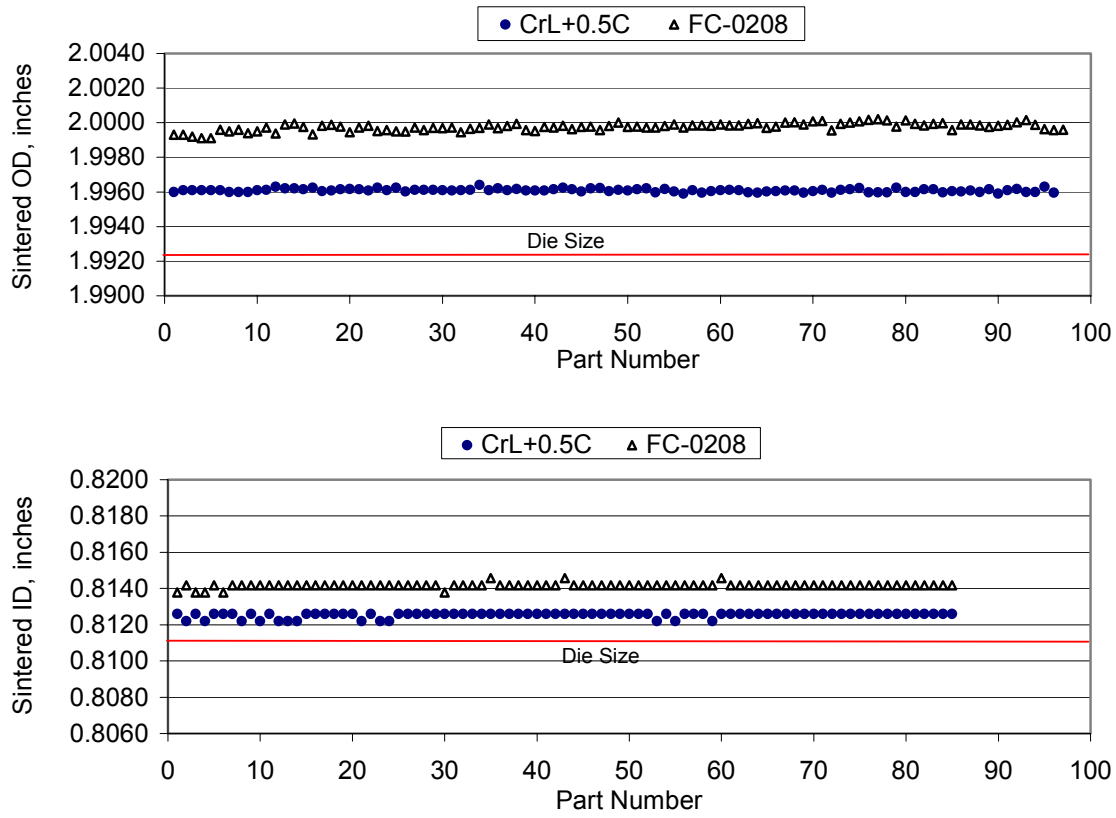


Figure 6 Variations in OD and ID dimensions of gears using CrL+0.5C and FC-0208 materials sintered under conventional sintering [2050°F(1120°C)@30min, 95/5 N_2/H_2]

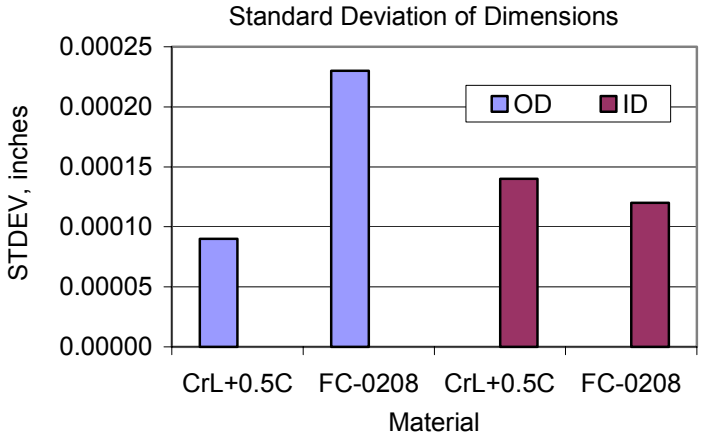


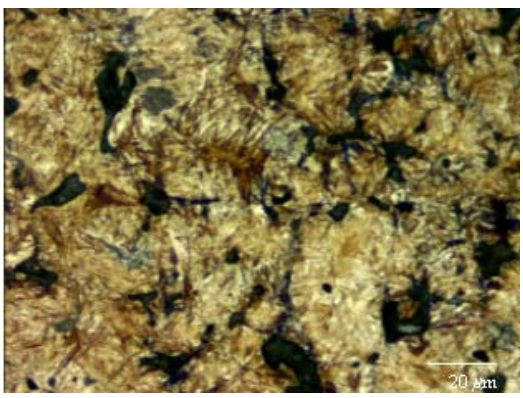
Figure 7 Standard deviation of gear dimensions of CrL+0.5C and FC-0208 materials sintered under conventional sintering [2050°F (1120°C)@30min, 95/5 N_2/H_2]

(2) Sinter-hardening

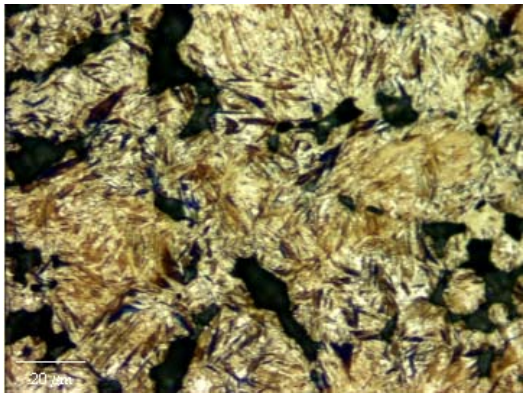
Microstructure and sintered properties

Sinter hardening has proven to be a cost effective process where the martensite transformation takes place during the cooling and therefore high strength and hardness can be achieved immediately after sintering. Alloying elements are utilized to promote the formation of martensite and/or bainite during cooling from sintering temperature. Prealloyed steel powders have been proven to be more useful for sinter hardening than admixed alloying elements because the alloying elements are fully dissolved in the iron matrix and a homogenous microstructure can be achieved after sintering. Molybdenum and Chromium are more efficient elements to improve hardenability of steels while the effect of nickel is significantly lower (1).

In this study, the CrL+Cu+C material (Astaloy CrL+1.0%Cu+0.73%C) was sintered under sinter hardening conditions as compared to the FLC-4608, a conventional sinter hardened material. Figure 8 shows the microstructures of CrL+Cu+C and FLC-4608 materials obtained under sinter hardening conditions. The CrL+Cu+C material has the similar microstructure as the FLC-4608 material, i.e. a almost fully martensitic structure. It means the Cr-alloyed material has comparable sinter hardening capability as the conventional sinter hardened steel even though it uses smaller amounts of copper and molybdenum and no nickel.



CrL+Cu+C (Astaloy CrL+1%Cu+0.73%C)



FLC-4608 (Fe+1.9%Ni+0.55%Mo+2%Cu+0.72%C)

Figure 8 Microstructures of CrL+Cu+C and FLC-4608 materials sintered under sinter hardening [2050°F(1120°C)@30min, 95/5 N_2/H_2 , 3~5°F/s(2~3°C/s) cooling rate, not tempered]

Table 3 shows the hardness results after sinter hardening. Even though the CrL+Cu+C material contains much smaller amounts of alloying elements than the FLC-4608, the CrL+Cu+C material is able to achieve an apparent hardness of 44 HRC that is comparable to the FLC-4608. The microhardness of the CrL material was much higher than that of the FLC-4608 material, indicating chromium has great hardenability. Mechanical property studies show the Cr-alloyed materials have equal tensile (UTS) and higher yield strength (YS) than Ni/Mo alloyed materials [see Figure 9] (4).

Table 3 Hardness comparison between CrL+Cu+C and FLC-4608 materials
[2050°F(1120°C)@30min, 95/5 N_2/H_2 , 3~5°F/s(2~3°C/s) cooling rate, not tempered]

	Sinter-hardening	
Material	CrL+Cu+C	FLC-4608
Sintered density, g/cm^3	7.00	6.95
Carbon content, %	0.73	0.72
Apparent hardness, HRC	44	43
Microhardness, Hv-$_{100g}$	843	671

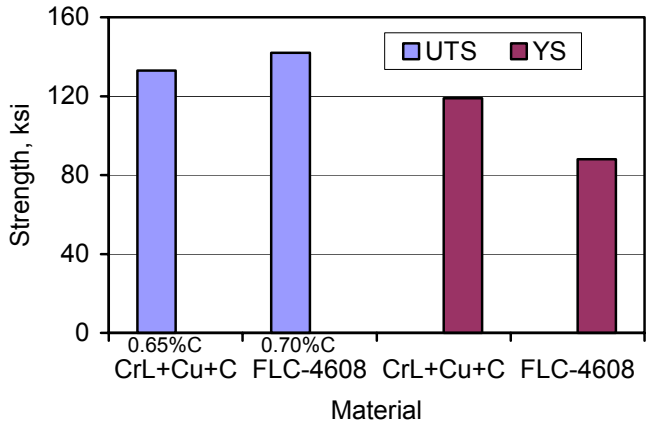


Figure 9 Mechanical properties of CrL+Cu+C and FLC-4608 materials compacted at 7.0 g/cm^3 with sinter-hardening [2050°F(1120°C)@30min, 90/10 N_2/H_2 , ~4°F/s(~2.2°C/s) cooling rate, tempered in air at 400°F(204°C) for 60min]

Dimensional tolerance

Figure 10 shows the average dimensional change of the gears using CrL+Cu+C and FLC-4608 materials after sinter hardening. The CrL+Cu+C material has less dimensional changes in both OD and ID dimensions than the FLC-4608 material. The difference in dimensional change is because the CrL+Cu+C material contained less copper content.

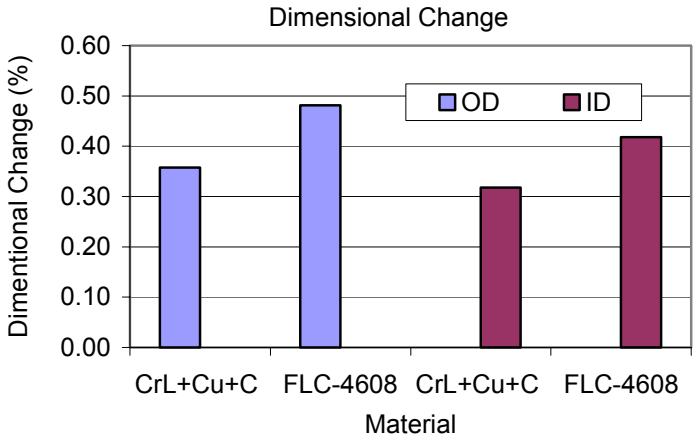


Figure 10 Average dimensional changes in OD and ID of gears using CrL+Cu+C and FC-0208 materials sintered under sinter hardening [2050°F(1120°C)@30min, 95/5 N_2/H_2 , 3~5°F/s(2~3°C/s) cooling rate, not tempered]

Figure 11 shows the variations in the dimensions of gears using these two materials and Figure 12 shows the standard deviation of gear dimensions using these two materials. It can be seen that the CrL+Cu+C material has reproducibility of dimensions and stability of dimensional change equal in ID dimension and better in OD dimension than the FLC-4608 material. The better dimensional control is because the CrL+Cu+C material contains less alloying amount, especially less admixed copper content.

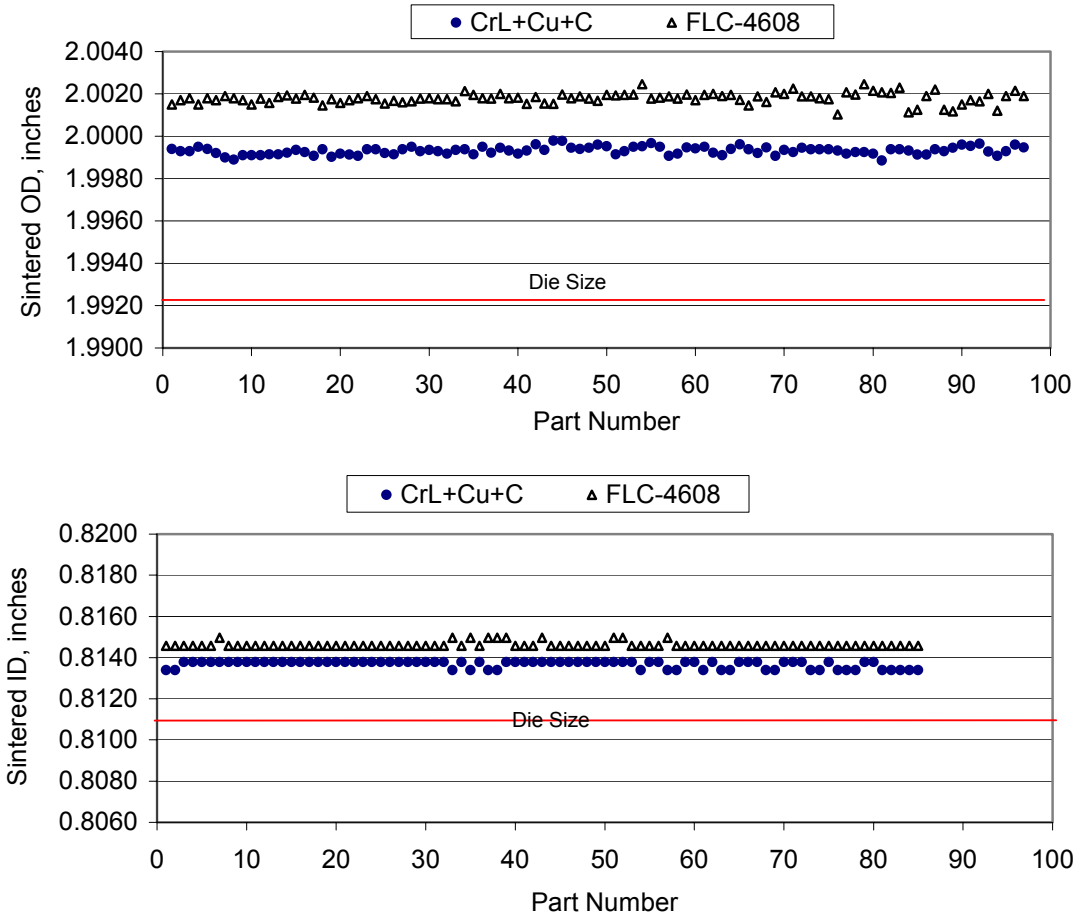


Figure 10 Variations in dimensions of gears using CrL+Cu+C and FLC-4608 materials sintered under sinter hardening [2050°F(1120°C)@30min, 95/5 N_2/H_2 , 3~5°F/s(2~3°C/s) cooling rate]

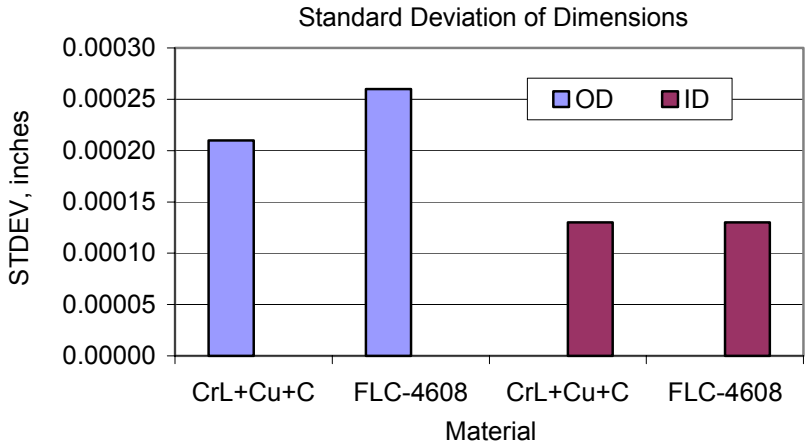


Figure 11 Standard deviation of gear dimensions of CrL+Cu+C and FLC-4608 materials sintered under sinter hardening [2050°F(1120°C)@30min, 95/5 N_2/H_2 , 3~5°F/s(2~3°C/s) cooling rate]

CONCLUSIONS

Based on the evaluation of the dimensional capability using Cr-alloyed materials verses conventional P/M alloyed materials through practical sintering production tests, the following conclusions were obtained.

Conventional Sintering

1) The CrL-alloyed material can achieve mechanical properties equal or higher than Fe-Cu materials while using much less carbon content and no copper addition.

2) The CrL-alloyed material provides better dimensional control than the Fe-Cu material due to the elimination of copper and reduced carbon addition.

3) The CrL-alloyed material allows a more reproducible product dimension and a more stable dimensional change than the Fe-Cu material because it is a prealloyed powder without the disturbance of admixed alloying element.

Sinter hardening

1) The CrL-alloyed material has similar sinter hardening capability to the Ni/Mo alloyed material due to the excellent hardenability of chromium.

2) The CrL-alloyed material has comparable mechanical properties to the Ni/Mo alloyed materials while using much less alloying amount.

3) The CrL-alloyed material provides less dimensional change than the Ni/Mo alloyed material due to reduced copper addition.

4) The CrL-alloyed material has better reproducibility of dimensions and stability of dimensional change than the Ni/Mo alloyed material.

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