Performance Characteristics of Newly Developed Ni-Mo Sinter-hardened PM Steel

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Abstract

Sinterhardening of PM components has been a successful and cost effective alternative to secondary heat treatment by eliminating the Heat Treatment manufacturing step. However, Sinterhardening alloys have been facing increased cost pressure due to the increases and fluctuations in the prices of molybdenum and nickel. Sinter-hardened components can also be susceptible to dimensional inconsistency due to the presence of admixed copper. The purpose of this paper will be to present the properties achievable with a newly developed sinter-hardening grade based on 0.9%Mo/0.9%Ni/0.25%Mn. The sinter-hardened material properties achieved on test pieces and production components will be evaluated. The new material is also manufactured in a version with 2% Cu diffusion alloyed. The dimensional consistency of the diffusion alloyed grade on production based components will be compared to traditional Sinter-hardened grades such as FLC-4608HT.

Introduction

The process of Sinterhardening has been an established one in excess of 15 years within the field of Powder Metallurgy. The process can potentially eliminate the secondary heat treat process for applications demanding only intermediate hardness levels, i.e. HRC 25 to 40, hence, achieving greater cost effectiveness.

Modern Sinterhardening furnaces achieve cooling rates of approximately 2 to 4C/s (4-6F/s) which is a significantly slower rate than achieved with oil quench for tradition hardening processes. Therefore one pre-requisite of sinter-hardening materials is a relatively high alloy content (relative to HT materials), which when combined with the relatively slower cooling rate (compared to oil quenching), achieves sufficient system hardenability to produce the desired microstructure, i.e. predominantly martensite, hence the required level of hardness and mechanical properties.

During the last two or three years however, the global market for alloying elements has experienced unprecedented volatility and price increases, see Figure 1 showing historical market development [1].

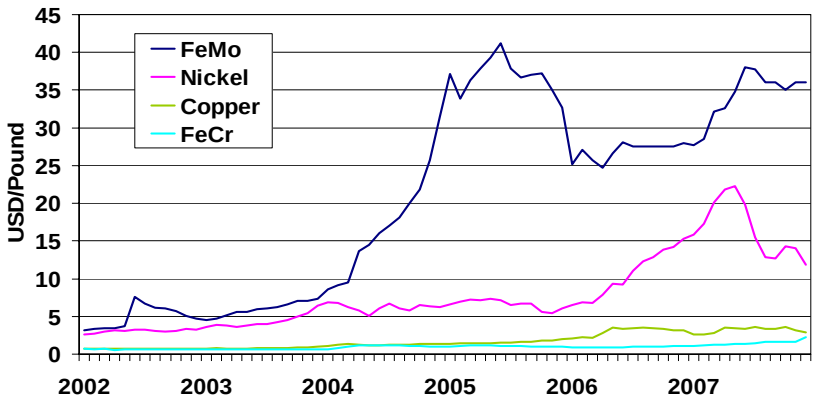


Figure 1 Historical price development of key alloying elements for PM

The combined effect of alloying element market volatility and that traditional sinter-hardening alloys are relatively rich in alloy content, has had a significant negative impact on the profitability of applications employing such materials, for the whole value chain. This has obviously led to customer and end user (application design responsible) demands / needs for greatly improved cost effectiveness in alloy design for sinter-hardening materials.

Cr- Material Development

The relative price stability of Cr as an alternative alloying element to Ni and Mo (and potential instability of Ni and Mo) was recognised by Hoganas Group back in the early to mid 1990's and prompted the development of P/M alloys systems based on Cr as a primary alloying element. The first alloy launched in the Cr-series was Astaloy CrM™ (MPIF Std 35, FL-5305), based on Iron fully pre-alloyed with 3.0% Cr and 0.5% Mo. The second alloy in the Cr family to be launched was Astaloy CrL (MPIF Std 35, FL-5208). Both the Astaloy CrM and the Astaloy™ CrL materials have been manufactured and marketed by Hoganas Group since 1999. Since then their market penetration has grown steadily and to date several thousand metric tons are used annually in varying applications. In addition further new materials in the Cr family are currently being launched from Hoganas Group.

Apart from the high performance levels achievable with the Hoganas Cr-alloys, it is this combined with cost effectiveness that is driving the growth of these alloys, see figure 2 below [2].

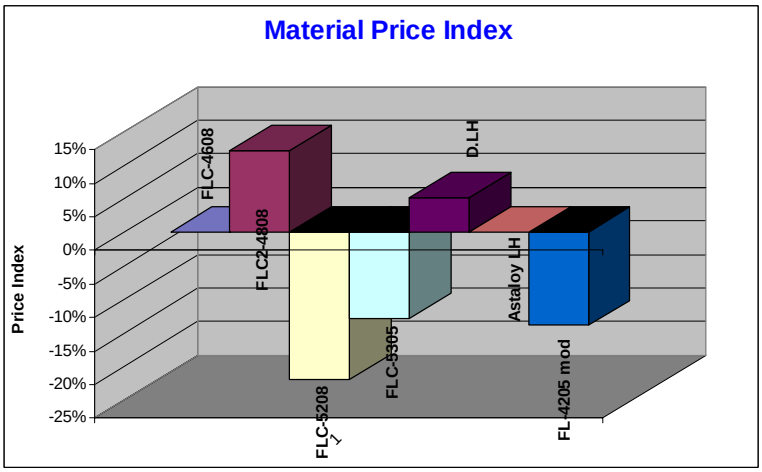


Figure 2, Relative Price Index for commonly used sinter-hardening PM materials

As Figure 2 depicts, Cr materials FL-5208 (Astaloy CrL) and FL-5305 (Astaloy CrM) offer significant cost effectiveness (with similar technical performance) compared to traditional sinter hardened alloys such as FLC2-4808, FLC-4608, etc.

Development of New Lean Sinter-hardening grade, Astaloy LH / D.LH

Although the Cr- materials from Hoganas group offer the optimum cost – performance ratio, there is still a market segment for an intermediate product satisfying one or all of the following needs:

- Similar performance to FLC2-4808, with substantially improved cost effectiveness
- Similar cost effectiveness to FLC-4608, but with significantly improved compressibility
- Cost effective alternative for PM manufacturers currently unable to process Cr bearing materials

This paper sets out to demonstrate the properties achievable with the new materials Astaloy LH and D.LH.

Experimental Procedure

Materials

Three different material systems were analyzed for the purpose of this investigation;

- Astaloy A (FLC-4608), reference material (as it is a popular alloy choice for Sinterhardening)
- Astaloy LH
- D.LH

Astaloy LH and Astaloy A are pre-alloyed materials while D.LH is a diffusion alloyed material. The chemical compositions of the base irons used is reported in Table I, whilst that of the mixes investigated are shown in Table II.

Table I. Chemical Composition of the Investigated Base Irons

Base Iron	Ni (%)	Mo (%)	Cu* (%)	Mn (%)
Astaloy LH	0.90	0.90	-	0.20
Astaloy A	1.90	0.55	-	0.20
D.LH	0.90	0.90	2.0	0.20

*Diffusion Bonded

Table II. Chemical Composition of Investigated Mixes

Mix #	MPIF Designation	Base Iron	Cu (wt%)	Graphite (wt%)	Lubricant (wt%)
1	-	Astaloy LH	2	0.85	0.75
2	-	Astaloy LH	2	0.75	0.75
3	-	D.LH	-	0.85	0.75
4	FLC-4608	Astaloy A	2	0.85	0.75

Note: Graphite Asbury 1651 and ACu Powder copper -165 mesh were admixed with the base irons. Kenolube was used as the lubricant.

Specimens Produced
For each mix, 1 to 4, test bars were compacted to green densities of 6.70 g/cm3, 6.90 g/cm3, and 7.10 g/cm3 in a 60ton hydraulic compaction press. The test bars compacted were transverse rupture strength test bars (MPIF-41), tensile strength test bars (MPIF-10), and impact energy test bars (MPIF-40).

Test slugs were compacted to a green density of 6.80g/cc g/cm3 from Mix 1 (Astaloy LH + 2%Cu + 0.85%C) for a mass effect analysis. The slug sizes used are shown in Table III.

Test rings were compacted to a green density of 6.80 g/cm3 from Mixes 1, 3, and 4 for a dimensional scatter analysis. The dimensions of the ring are 55mm OD x 35mm ID x 20mm height. A picture of the ring is shown in Figure 4 and a picture of the mass effect pucks in figure 3 below.

Table III. Slug Sizes for Mass Effect Study

Slug ID	OD (mm)	Height (mm)
A	25	25
B	50	50
C	75	50



Figure 3 Photographs of the mass effect parts

The aim of utilising the three separate samples is to provoke mass effects to take place during the sinter hardening and evaluate the sensitivity of the materials hardenability to mass effect.

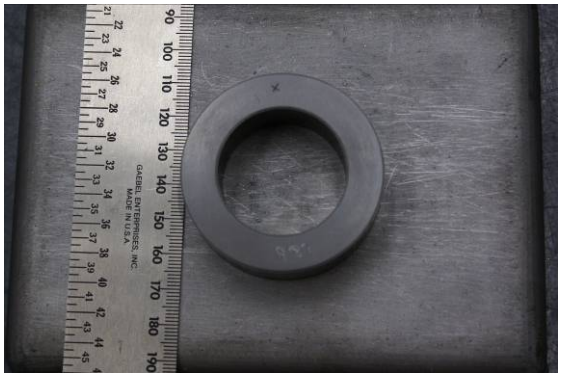


Figure 4 Ring Compacted for Dimensional Study

The dimensional study aimed to compare the dimensional change consistency between the powder grades, i.e. to quantify the scatter obtained with Astaloy LH + 2%Cu admixed, D.LH (where Cu is diffusion bonded), and FLC-4608 also containing 2% admixed Cu.

Processing Conditions

The test bars for each material system were sintered for 20 minutes at 1120°C (2050°F) in a 90% N2 / 10% H2 atmosphere. The sintering was carried out in a 152mm (6”) Abbott laboratory belt furnace equipped with a Varicool convection cooling system. The frequency of the cooling systems was set at 0Hz and 60Hz. All sinter-hardened test bars were tempered for 1 hour at 204°C (400°F) in air.

The test slugs and rings were sintered for 20 minutes at 1120°C (2050°F) in a 90% N2 / 10% H2 atmosphere. The sintering was carried out in a 152mm (6”) Abbott laboratory belt furnace equipped with a Varicool convection cooling system. The frequency of 60Hz was used during sintering. All slugs and rings were tempered for 1 hour at 204°C (400°F) in air.

Testing

After processing, apparent hardness, dimensional change, sintered density, sintered carbon, and transverse rupture strength were evaluated on the TRS bars. Tensile and impact properties were evaluated on the tensile and impact bars. The test rings were measured for outer diameter.

Metallography

Impact energy bars were prepared for metallographic analysis. Photomicrographs were taken of the structures after etching with 3% Picral. The mass effect slugs were evaluated at the surface and centre of each slug to determine hardenability.

Results and Discussion

Note that all data is presented with diagrams and data for Zero Hz Varicool frequency and 60Hz. This is to show the effect of effectively no forced convective cooling (i.e. zero Hz) and standard sinter hardening cool rate produce with setting the system to 60Hz.
Furthermore all responses are plotted against density.

Compressibility

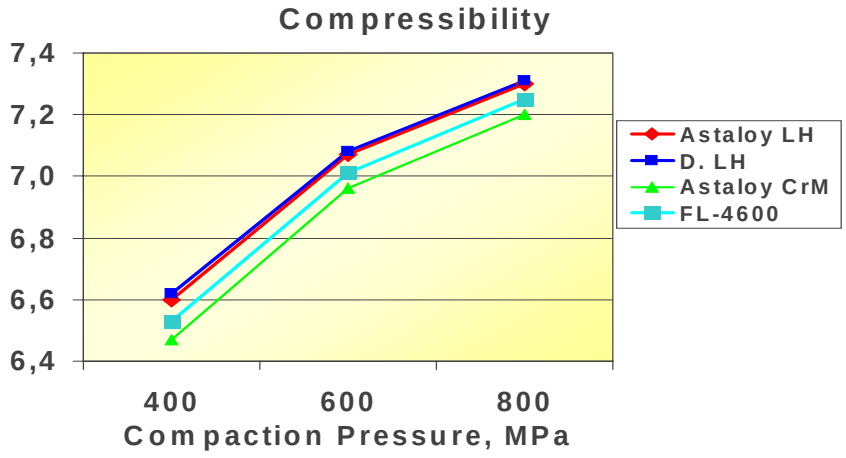


Figure 5 Compressibility curves comparing Astaloy LH, D.LH, Fl-4600 and FL5300.

The compressibility of the new Astaloy LH and D.LH grades are significantly higher than for FLC4600 and FL-5300. Low compressibility of sinter-hardening grades is one of their drawbacks as they are often heavily pre-alloyed and these substitutional elements decrease compressibility. Hence this is one of the main advantages for Astaloy LH and D.LH.

Dimensional Change

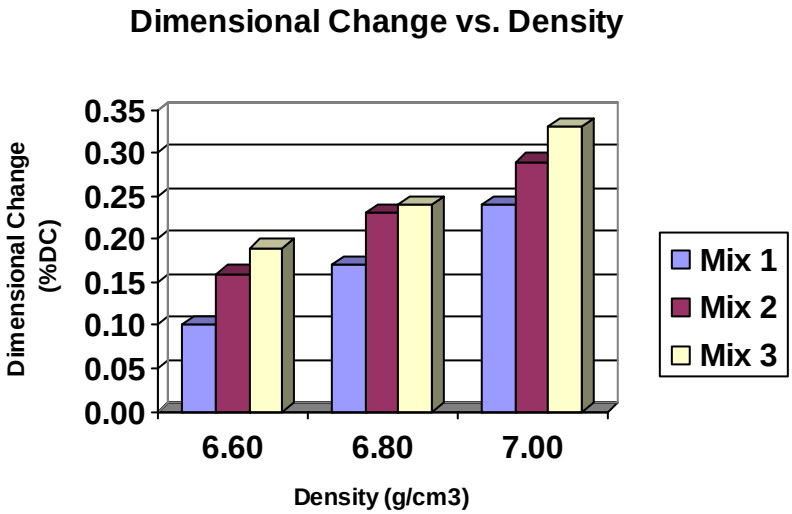


Figure 6, Dimensional Change at Zero Hz Setting

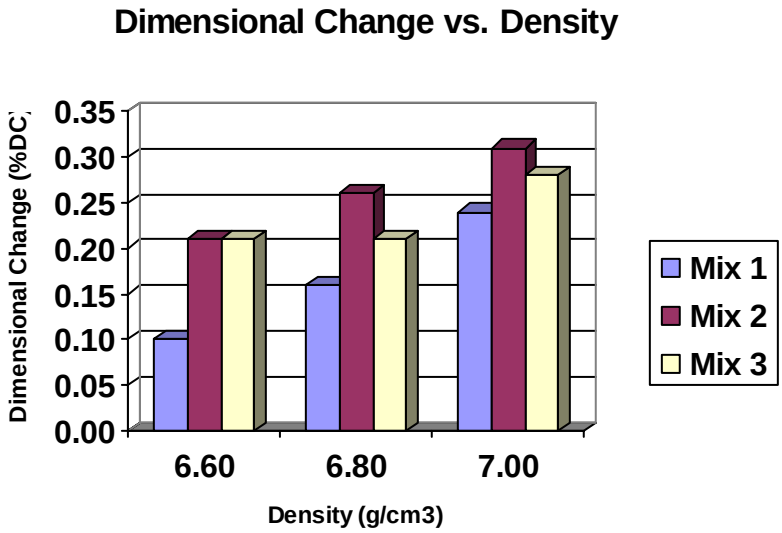


Figure 7, Dimensional Change at 60 Hz Setting

Typically for this type of alloy system swelling occurs during sintering and this can also be regarded as a slight negative effect upon application performance. Also important to note is that the swelling has a directly proportional relationship with density.

Mechanical Properties

Hardness

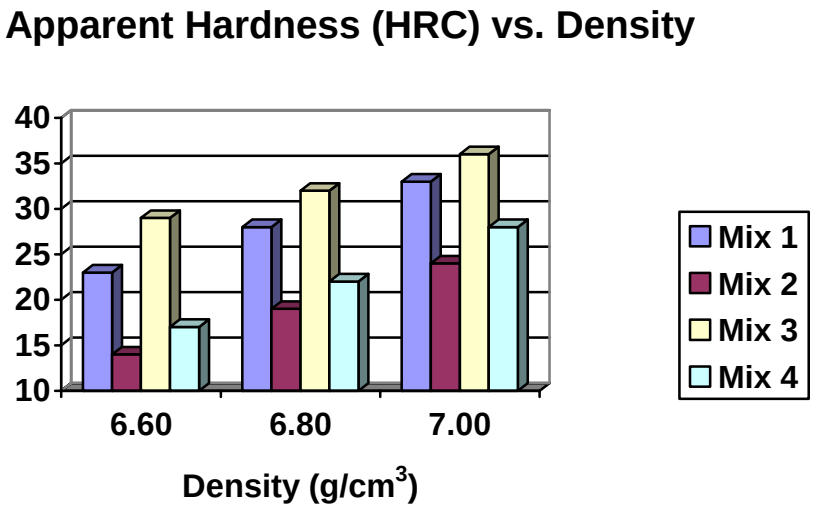


Figure 8, Hardness at Zero Hz Setting

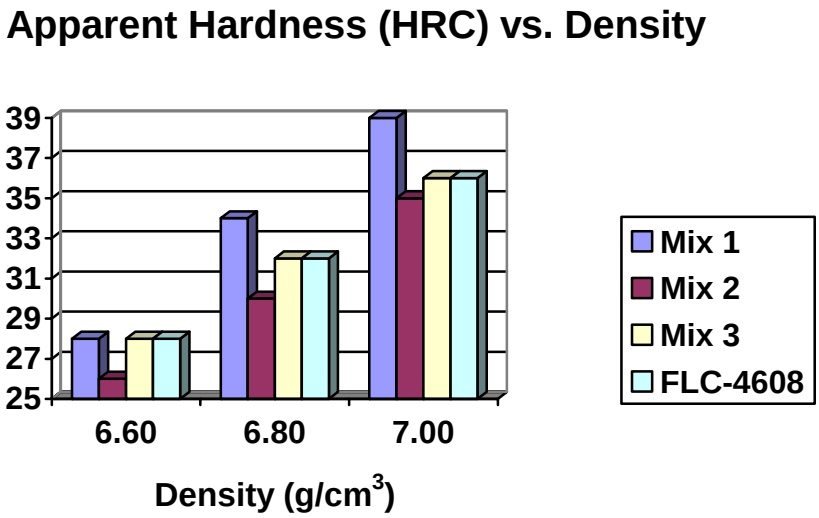


Figure 9, Hardness at 60Hz setting

When running at a normal cooling rate (i.e. without sinter hardening cooling – Zero Hz) reasonable hardness can be achieved with Astaloy LH and D.LH as compared to FLC-4608, ranging between HRC 25 – 30 at 6.80g/cc. Already from the hardness data it is apparent that increased hardness is achieved with 0.85%C.

Increasing the cooling rate to a sinter hardening rate (i.e. at 60Hz) then the achievable hardness increases as expected.

Transverse Rupture Strength (TRS)

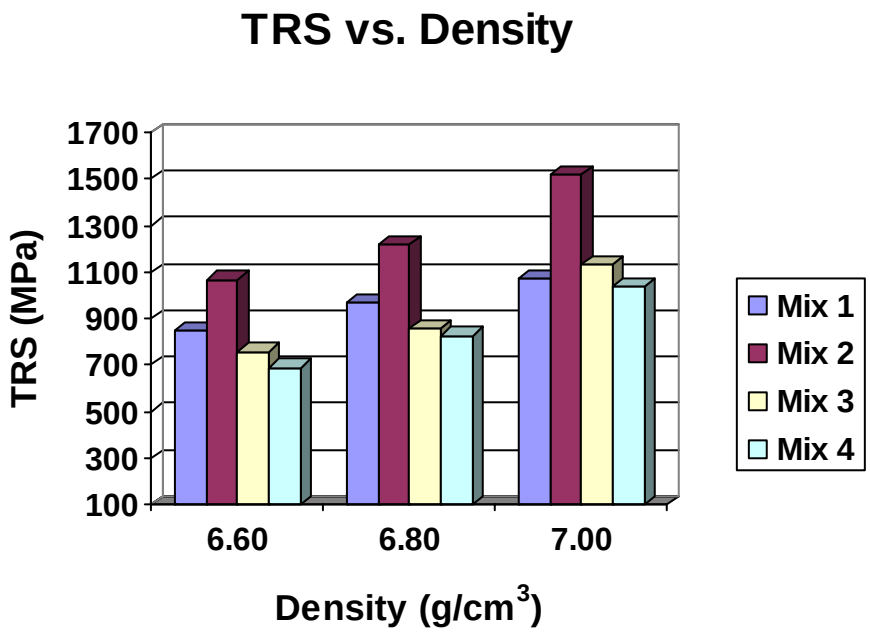


Figure 10, TRS at Zero Hz Setting

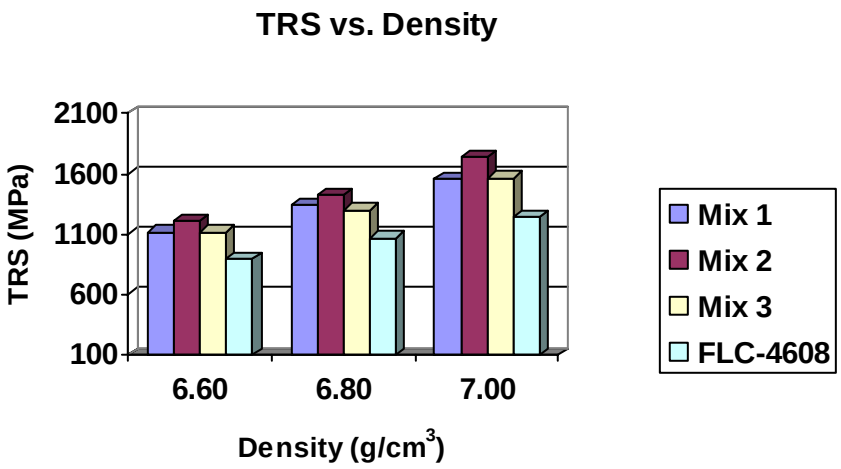


Figure 11, TRS at 60Hz setting

Not surprisingly the maximum transverse rupture strength is obtained when using the lower graphite content of 0.75% as opposed to 0.85%. Levels in excess of 1100MPa are obtainable when used with 60Hz cooling speed.

Ultimate Tensile Strength (UTS)

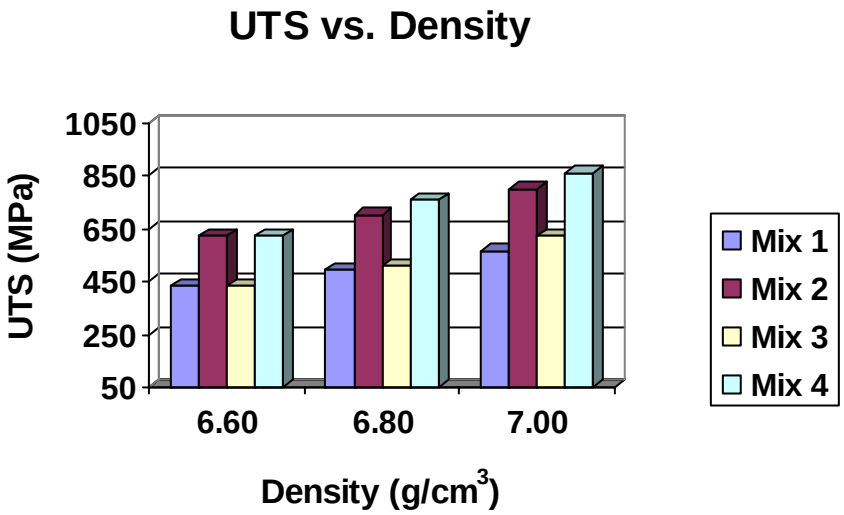


Figure 12, UTS at Zero Hz Setting

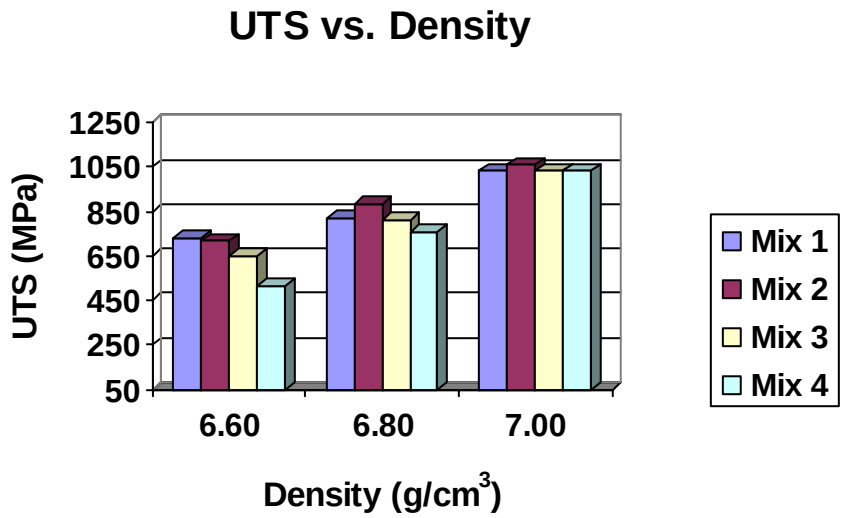


Figure 13, UTS at 60Hz setting

The ultimate tensile strength for the materials is rather similar for the sinter-hardening cooling rate and at 7.00g/cc sintered density.

Impact Energy (IE)

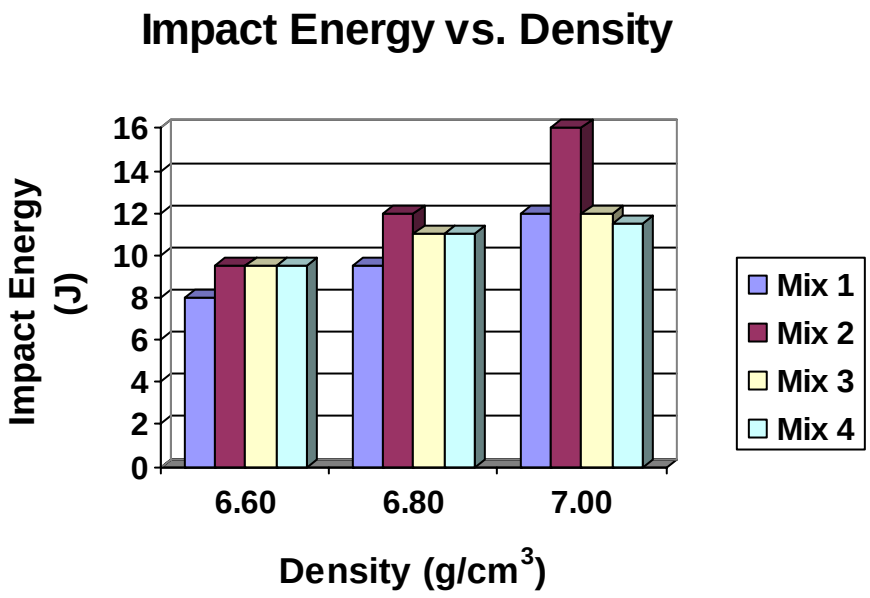


Figure 14, IE at zero Hz setting

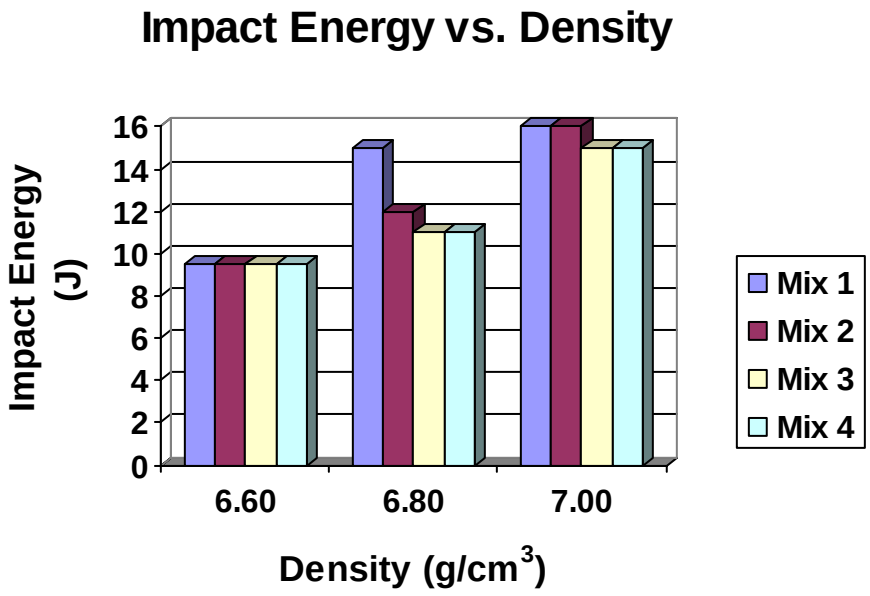


Figure 15, IE at 60 Hz setting

There were no significant differences between the impact energy levels obtainable for all materials.

Microstructures

The microstructures are as expected for the material (Astaloy LH + 2%Cu + 0.85%C), at zero Hz frequency (in effect without sinter hardening cooling rate) the resultant microstructure is martensite matrix with bainite islands, figure 17. For the 60 Hz frequency the microstructure is fully martensitic, figure 18. Note the light coloured regions are simply etching effects, they are martensite areas too.

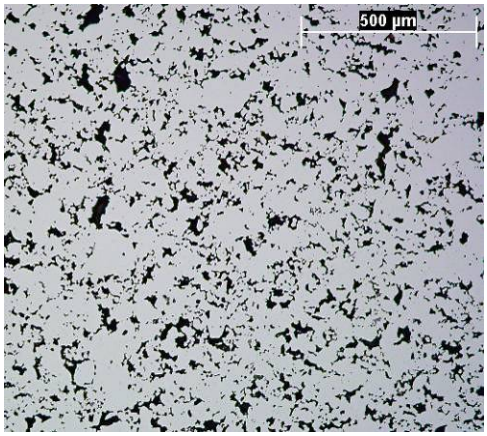


Figure 16 Un-etched microstructure at 6.80g/cc sintered density

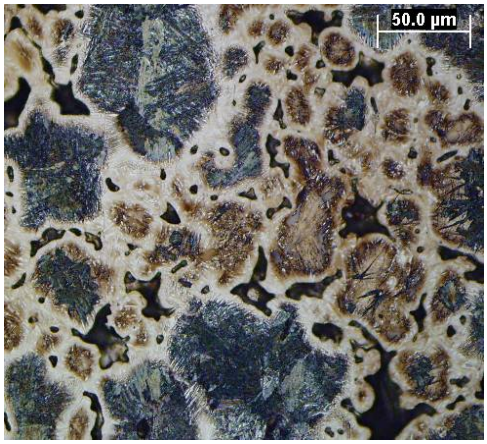


Figure17 Etched Microstructure at zero Hz setting

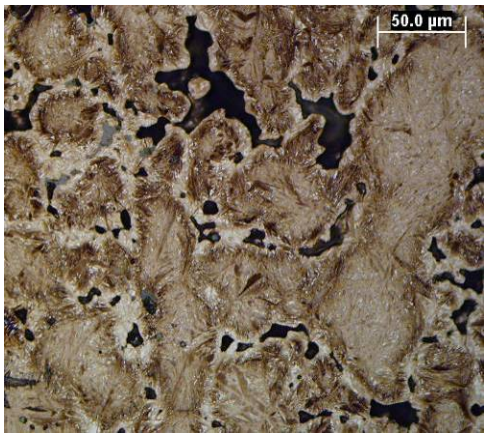


Figure 18 Etched Microstructure at 60Hz setting

Mass Effect

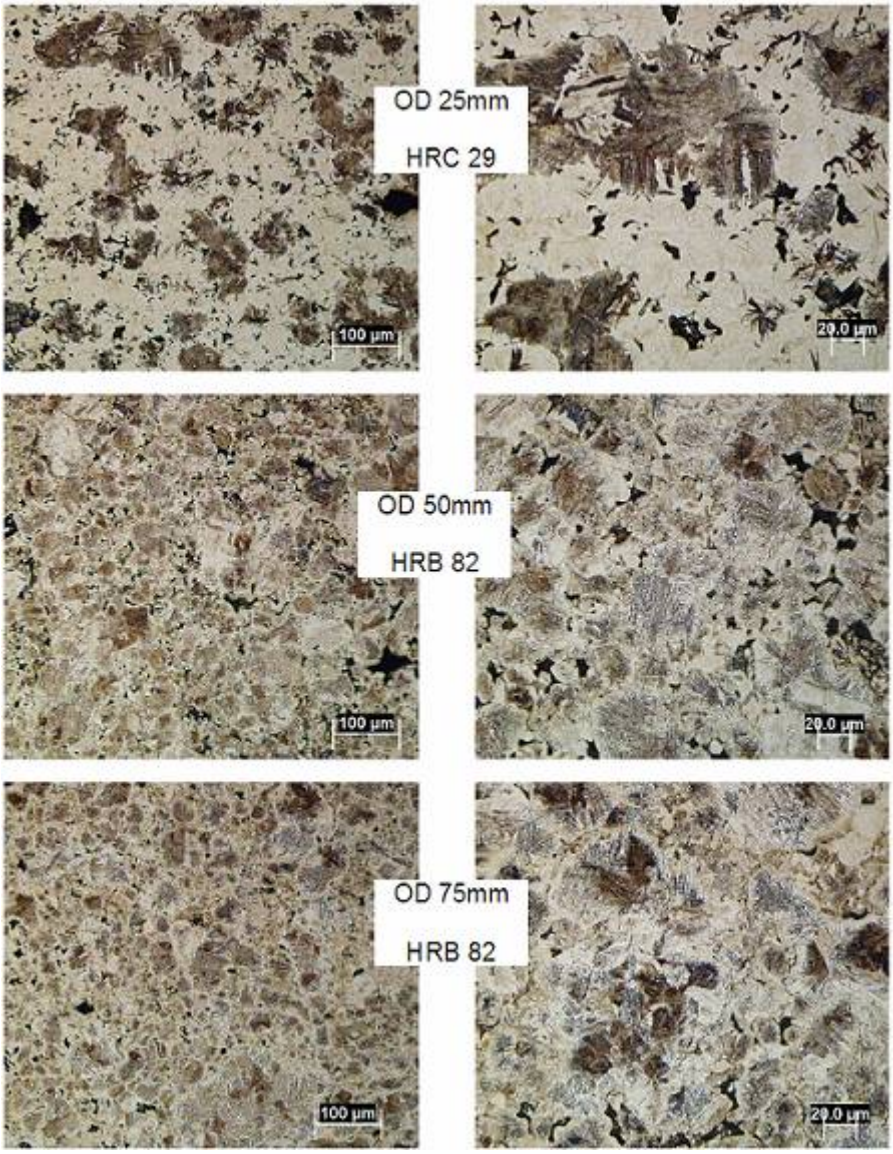


Figure 19, Mass Effect of Astaloy LH + 2%Cu + 0.85%C, Cooled @ Zero Hz

The microstructures above display those of the different specimen sizes at zero Hz cooling (i.e. effectively with normal cooling rate of around 1C/s. Not surprisingly it is clear that as the mass of the part increase from OD 25 to OD 50 to OD 75, and then the amount of bainite increases and the hardness drops in direct relation.

For the OD25 specimen (smallest mass) the microstructure shows Martensite with approximately 20% Bainite, and the hardness is on average HRC 29. For the OD 50 and 75 specimens the microstructures consist of Bainite + Pearlite, with less amounts of Martensite and this is also reflected in the reduced apparent hardness of HRB 82 (not possible to measure on HRC Scale).

Obviously this indicates that when using a standard cooling rate (i.e. a furnace not equipped with forced convective cooling), care must be taken to ensure that the maximum section thickness within a component will transform to the desired microstructure giving the desired properties.

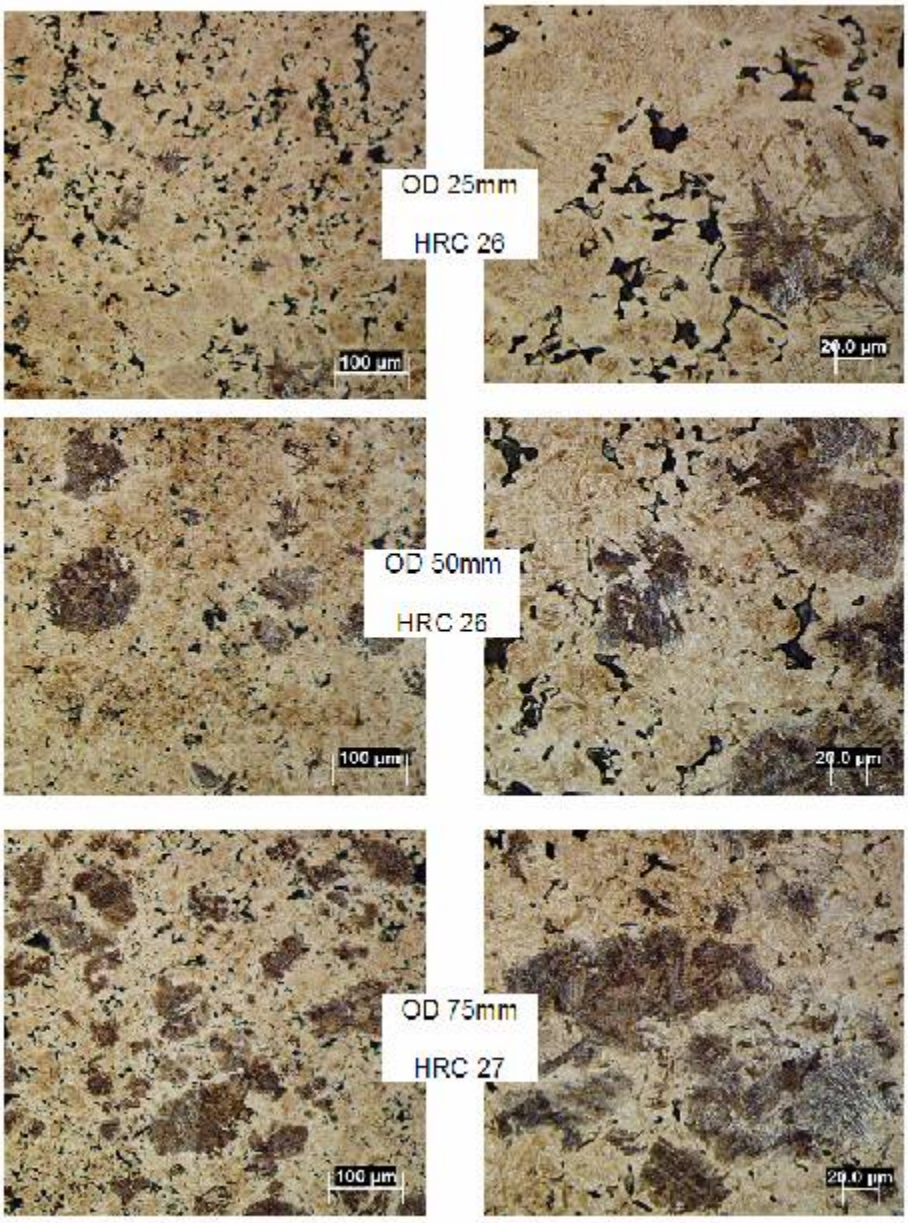


Figure 17, Mass Effect of Astaloy LH + 2%Cu + 0.85%C, Cooled @ 30Hz

When the mass effect specimens were processed at 30Hz cooling the it is clear to see that good transformation takes place for all the specimen sizes showing that the hardenability of the material is sufficient. The OD25 specimen exhibits 100% Martensite where as the OD 75 specimen exhibits Martensite with around 20% Bainite. However, the apparent hardness doesn't show any apparent deterioration, achieving HRC 26-27 on average. Hence, the hardenability of Astaloy LH / D.LH + 0.85%C when combined with sinter hardening cooling rates of 30Hz and above will be sufficient to give desired microstructure and properties.

Dimensional Consistency Study

Whilst sintering the ring specimens for the dimensional consistency study furnace problems were experienced and the specimens were deemed to be unreliable due to this mishap. Therefore the purpose of this study this data can not be presented at this time.

Therefore it was not possible in this paper to demonstrate that D.LH (where Cu addition is diffusion bonded to avoid segregation and avoid scatter in DC) will demonstrate superior performance with respect to reduced dimensional scatter, as intended.

Conclusions

- Sinter hardening materials have come under severe cost pressure due to rising costs of alloying elements
- Astaloy CrL and Astaloy CrM are Hoganas primary solutions for cost effective sinter-hardening materials
- However, where issues with utilising Cr materials occur, Astaloy LH and D.LH provide sinter hardening materials with an intermediate cost – performance level.
- Achievable properties for Astaloy LH + 2% Cu + 0.85%C, at 6.80g/cc and cooled at 60Hz are
    - DC + 0.15%
    - HRC 30
    - TRS >1100MPa
    - UTS 850MPa
    - IE 14J
    - Mass Effect – full transformation for thicker sections
- It wasn't possible to confirm the reduced dimensional scatter of the diffusion bonded version, D.LH, as experimental problems occurred.

References

1. Hoganas Iron Powder Handbooks

2. Howe, I and Forsum, M. (2008) 'Lean sinter materials point way towards greater profitability', Metal Powder Report, No 4 April 2008, pp. 32-34.