Dimensional Precision in Sinter-hardening PM Steels

Bruce Lindsley[a] and Thomas Murphy[b]

Hoeganaes, 1001 Taylors Lane Cinnaminson, NJ 08077 USA
[a]Bruce.Lindsley@hoeganaes.com, [b]Tom.Murphy@hoeganaes.com

Abstract

Dimensional precision is a critical parameter in net shape processing of ferrous PM components. Sinter-hardening alloys undergo a transformation from austenite to martensite. Martensite formation expands the sintered compact, while tempering hardened steels results in shrinkage. In addition, martensitic regions with high Cu and C contents may contain large amounts of retained austenite. The presence of martensite and retained austenite, in addition to the tempering step, all play a role in the final dimensions of a component. This paper investigates the dimensional and microstructural changes to two sinter-hardening grades through different post-sintering thermal treatments.

Keywords : Dimensional Control, Sinterharden, Dilatometry, Tempering

1. Introduction

Dimensional change in ferrous sintered compacts is influenced by composition and cooling rate, which play an important role on microstructure and mechanical properties. Previous studies detail the effects of composition on dimensional change of sinter-hardenable steels [1,2]. Sinter-hardening utilizes alloyed steels and/or accelerated cooling rates to achieve fully hardened, martensitic structures directly out of the sintering furnace. Austenite is often present in these microstructures in heavily alloyed regions (retained austenite). Austenite is the highest density phase of steel, while martensite is the lowest density phase. This decrease in density results in a corresponding increase in compact growth. Length changes in pore free materials can reach 1.4% upon transformation from austenite to martensite [3]. Tempering of martensite leads to a ferrite and carbide structure, which has a higher density. The post sintering operation of tempering should therefore decrease the dimensional change of a martensitic sintered compact. Transformation of retained austenite, however, will result in compact growth. The purpose of this paper is to investigate the effects of post-sinter processing on the dimensional change and microstructure of sinterhardened steels.

2. Experimental and Results

Table I. Nominal compositions (in wt.%)

Alloy	Designation	Ni	Mo	Mn	Cu	C
1	FLC2-4808	1.4	1.25	0.4	2	0.8
2	FLNC-4408	2	0.8	0.1	1.5	0.8

The two alloys studied were FLC2-4808 (Ancorsteel® 737 + 2% Cu + graphite) and FLNC-4408 (Ancorsteel 85HP + 2% Ni + 1.5% Cu + graphite). The compositions are listed in Table I. The mixes were compacted into standard TRS and dilatometry test specimens at a compaction pressure of 690 MPa. The samples were sintered in a 90% nitrogen – 10% hydrogen atmosphere at 1120 °C for 15 minutes at temperature. Accelerated cooling was used to achieve a cooling rate of 1.6 °C/sec. Tempering was carried out at 205 °C for the majority of test conditions. After sintering, samples were subjected to a variety of tempering (T) and liquid nitrogen quench (LNQ) operations: 1. as-sintered, 2. LNQ, 3. T/1hr, 4. LNQ + T/1hr, 5. T/1hr + T/1hr, 6. T/1hr + LNQ, 7. T/1hr + T/1hr + LNQ, 8. T/4hr, 9. T at 225 °C/1hr. Dimensional change (DC) was measured from die size.

The as-sintered microstructure of the alloys is predominately martensitic with retained austenite (Figure 1). Figure 1a shows a typical martensitic microstructure, whereas Figure 1b shows the same field etched to reveal retained austenite. The majority of the retained austenite is directly associated with copper-rich regions. The dimensional change will be controlled by the tempering of martensite and the transformation of retained austenite.

The early stages of tempering involve 3 phenomena: 1) rapid stress-relieve and diffusion of C to dislocations at, 2) transformation of retained austenite to bainite, and 3) further C diffusion and formation of carbides above 200 °C [3]. The first and third phenomena involve a reduction in length, as martensite changes to bcc ferrite and carbide. The second produces a length increase, as the high density austenite phase transforms to lower density bainite. To demonstrate these three stages of tempering, dilatometry was run on sinter-hardened Alloy 1. Figure 2 shows the change in length with temperature and between 125 and 175
® Ancorsteel is registered trademarks of Hoeganaes Corporation

(a) 2% Nital / 4% Picral   (b) as (a), then $Na_2S_2O_5$ in H_2O
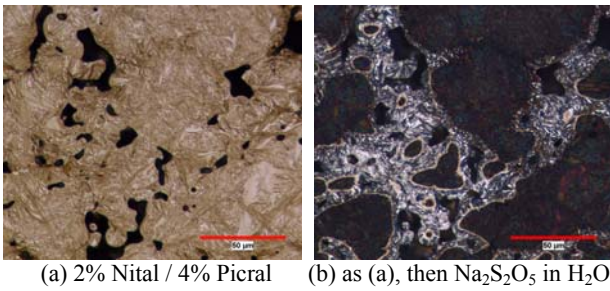
Fig. 1. Microstructure of the sinter-hardened Alloy 1 (FLC2-4808) etched to reveal (a) martensite and (b) retained austenite (white) in Cu-rich regions (same field).

Fig. 2. Tempering of Alloy 1 (FLC2-4808) in the dilatometer at 205 °C for 1 hour.

a   b

Fig. 3. Tempering of Alloy 1 at 225 °C a) after a liquid nitrogen quench and b) as-sintered.

°C, the slope is greatly reduced as a result of the first stage of tempering. During the 1 hour hold at temperature, a small amount of growth can be seen (see inset box) due to retained austenite transformation. Upon cooling, a reduction in sample length is observed (-0.09%). To better illustrate the tempering effects at temperature, two samples were heated to 225 °C to accelerate the dimensional changes (Figure 3). The first sample, quenched in liquid nitrogen prior to tempering, exhibited a larger length decrease (-0.14%) as a result of the third stage of tempering (Figure 3a). The sample that was not quenched in liquid nitrogen shows growth during the 225 °C hold as a result of retained austenite transformation to bainite. Overall, the sample length decreased by only -0.07%. By understanding these phenomena, the effects of post sintering treatments on DC and stability can be better understood in PM parts.

The dimensional change of Alloys 1 & 2 for the various thermal treatments is given in Table II. Both alloys have significant levels of retained austenite, resulting in growth (+0.13%) from the LNQ quench. Tempering of the martensite results in shrinkage, as seen by comparing conditions 3 and 4 relative to 1 and 2, respectively, in Table II. More shrinkage occurs during tempering of the LNQ sample, as there is no austenite transformation growth contribution. The double tempered sample and the sample tempered for 4 hours show growth relative to the single tempered sample as retained austenite transforms to bainite. Tempering prior to LNQ greatly reduces growth, conditions 6 & 7. This is consistent with a portion of the retained austenite transforming during the temper, and thereby less is present to transform to martensite during the LNQ. The T + T + LNQ has the same DC as T + LNQ. Given that the T + T operation had more growth relative to the T operation and thereby less retained austenite after tempering, it is expected that the T + T + LNQ will have more bainite and less martensite than the T + LNQ. The 225 °C temper for 1 hour resulted in both tempering of martensite and transformation of austenite, and is expected to be the most dimensionally stable sample of the single step operations.
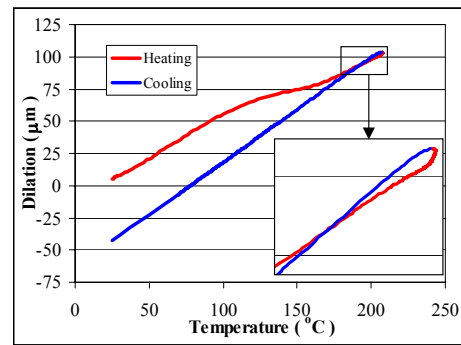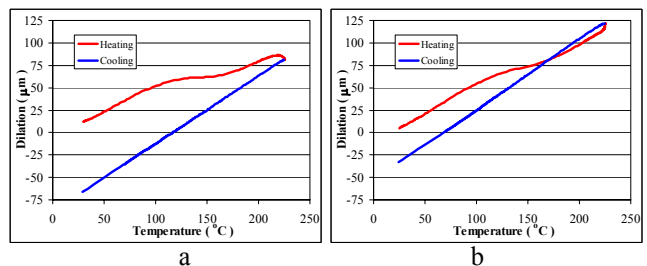
Table II. Dimensional change (%) of post sinter operations normalized to the as-sintered length

Alloy	1. As-Sinter	2. LNQ	3. T	4. LNQ + T	5. T + T	6. T + LNQ	7. T + T + LNQ	8. T/4hr	9. T/225°C
1	0	+0.13	-0.10	+0.01	-0.08	-0.05	-0.05	-0.07	-0.06
2	0	+0.13	-0.06	+0.04	-0.04	+0.01	+0.01	-0.03	-

3. Summary

The effect of different post-sintering thermal treatments on dimensional change was investigated. Tempering of martensite reduces growth and improves the dimensional stability of the material. The presence of retained austenite can lead to dimensional instability. If cooled to low temperature, the austenite transforms to untempered martensite, resulting in large growth. If heated to a high enough temperature, the austenite transforms to bainite. The most dimensionally stable structure will contain little to no retained austenite and well tempered martensite.

4. References

[1] B. Lindsley, G. Fillari, and T. Murphy, PM2TEC2005, MPIF, Princeton NJ, 2005 p. 10-353.
[2] B. Lindsley and T. Murphy, PowderMet2006, MPIF, Princeton NJ, 2006.
[3] R. E. Reed-Hill, Physical Metallurgy Principles – 2nd Edition, PWS-Kent Publishing, Boston, MA, 1973, p. 701.