ASYMMETRICAL TRANSFORMATION IN DIFFERENT TYPES OF PURE IRONS
ON PROF. H. DANNINGER'S DETAILED OBSERVATION OF SINTERED IRON

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Abstract
The development of extremely coarse α grains in sintered plain iron is compared with that in cast pure iron. This development is related not to any special factor in powder metallurgy, such as invisible neck or pore structures, but is proposed to be related to the principal characteristic of the allotropic transformation in iron with very low interstitials.
Keywords: coarse ferrite, columnar ferrite, pure iron, transformation

GENERAL CONSIDERATION ON CAST AND SINTERED PURE IRONS

The development of very coarse and columnar α grains throughout γ-α transformation has often been observed over about half a century [1-10]. α grains grow extremely fast in pure irons [7]. The formation of nuclei may be limited since the sites for such formation are few in pure irons. Once an α nucleus is formed, it may grow to a very coarse grain covering and joining many γ grains [4]. Naturally, coarse grains may become columnar under a temperature gradient [1,3,5,9,11].

Carbonyl iron compacts sintered in H_2 to density ranges near and more than 7.1 $g.cm^{-3}$ and to a carbon content of less than 150 ppm show coarse α grains. The grains in the compacts with less than 40ppm of carbon grow along thermal flow during cooling from the cool side to the hot side, forming columnar structures throughout γ-α transformation [6].

Similar coarse α grains also appear in different types of sintered iron from other powders of below 100 mesh class including reduced-ore-, reduced-millscale-, water-atomized- and electrolytic-iron powders [12]. Carbon content in sintered irons tends to be extremely low due to decarburizing by surface oxide on powder particles [6].

Carbon and nitrogen, even if their total content is less than 100 ppm, may concentrate at α/γ boundaries, forming compounds in some cases. Phase boundaries rich in interstitial atoms in any form could be sites for the formation of new ferritic nuclei which could interrupt the growth of columnar grains, leading to the development of equiaxed grains [6,7].

The formation of coarse grains is prevented by the introduction of a small amount of carbon; in sintered irons, such formation is prevented by adding a very small amount of graphite [6], by trapping oil in porosity throughout the soaking and re-pressing [11], and by transporting carbon from a boat and/or a furnace structure containing a small amount of the element through the gas phase during heating [1,11].

DISCUSSION ON PROFESSOR DANNINGER'S OBSERVATION

Danninger's results may be summarized in four parts.

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Discrepancy of transformation

The shrinkage during α-γ transformation in the heating process is about 0.25 %, which is markedly smaller than the expansion of 0.6 % or larger of some compacts during γ-α transformation in the cooling process. Effects of various sintering atmospheres on the discrepancy of transformation compared to that attained by his standard rotary-pump-vacuum are as follows. Ar with a pressure of 600 mbar, which is lower than the atmospheric pressure, has slightly reduced the discrepancy. Low-pressure air has reduced the discrepancy more with an increase in the pressure. N_2 with various pressures has removed the discrepancy, giving percentages of shrinkage and expansion during the transformation similar to those of Armco iron, 0.30-0.31 %. The addition of 0.1 mass% graphite has also removed the discrepancy.

This can be explained as the controlling effect of interstitials in small amounts on the discrepancy of transformation. The reduction in discrepancy in Ar, particularly during repeated cycles, can suggest first the leaking of air or nitrogen into the furnace atmosphere, and secondly a kind of carburization from a surrounding structure containing carbon even at a level of a few hundred ppm through gas phase transportation.

Change of size and growth of columnar structure

The compacts that have shown the discrepancy have also shown an increase in their sintered size and an excessive α grain growth or a coarse columnar structure. On the contrary, the disappearance of the discrepancy has accompanied the formation of fine grains.

This indicates a close relationship between the transformation discrepancy and the excessive α grain growth.

Discrepancy and unidirectional transformation

The compact with a maximum discrepancy gave a maximum value of expansion, 0.95 %, during cooling transformation. The expansion was about 3 times larger than those of Armco iron, 0.30-0.31 %.

The ratio 3 suggests that the volume expansion of the sintered iron has caused a linear expansion under unidirectional cooling transformation with an unchanged section size of the rod sample. Coarse columnar α grains indicate unidirectional transformation, while an unchanged section size suggests the restricting effect by the former γ on newly developing α [13].

Carbon and oxygen

Based on the effect of the addition of a small amount of graphite on the removal of the discrepancy, Danninger supposed an effect of residual oxygen.

The formation of α columnar grains under a temperature gradient can be the characteristic transformation mechanism of pure iron. This characteristic may easily appear in interstitial-free or very pure irons. For the transformation discrepancy, the oxygen theory would be Ptolemaic which has been the first choice of many researchers, including the present author, while the pure-iron theory is Copernican.

CONCLUDING REMARKS

A pure iron heated or sintered in a γ temperature range presents an α structure, which has developed not in the γ temperature range, but throughout γ-α transformation. Extremely coarse α grains form in irons containing less than approximately 100 ppm of interstitials, carbon and nitrogen. Once an α nucleus is formed in such irons, including compacts prepared from various iron powders to a density of about 7.1 $g.cm^{-3}$ or higher, it may grow coarse, covering and joining many γ grains, and columnar by unidirectional transformation under a temperature gradient giving a linear expansion numerically equal to a volume expansion at the time of the event.

REFERENCES

[1] de Jong, M., Rathenau, GW.: Acta Metallurgica, vol. 5, 1957, p. 679
[2] Lehr, P., Langeron, J P.: Revue de Metallurgie, vol. 55, 1958, p. 829
[3] de Jong, M., Rathenau, GW.: Acta Metallurgica, vol. 7, 1959, p. 246
[4] Leymonie, C., Lebrun, Mlle, Cizeron, G.: Mem. Sci. Rev. de Metallurgie, vol. 63, 1966, p. 271
[5] Adam, Von P., Rohloff, H., Frohberg, G.: Arch. Eisenhuttenw., vol. 41, 1970, p. 1153
[6] Kuroki, H., Kobayashi, Y., Tokunaga, Y.: J. of the Jpn. Inst. of Metals, vol. 41, 1977, p. 920 (Abstract and captions in English)
[7] Shibata, K., Asakura, K.: ISIJ International, vol. 35, 1995, p. 982
[8] Ogawa, T., Harima, N., Takaki, S., Abiko, K.: Materials Trans., JIM, vol. 41, 2000, p. 95
[9] Ogawa, T., Harima, N., Takaki, S., Abiko, K.: Materials Trans., vol. 43, 2002, p. 129
[10] Tajima, S. et al.: Abstracts of Autumn Meeting of the Jpn. Soc. of Powder and Powd. Metall., 2003, no.1-45A
[11] Kuroki, H., Shirakawa, M., Tokunaga, Y.: J. of the Jpn. Soc. of Powder and Powd. Metall., vol. 22, 1976, p. 271 (Abstract and captions in English)
[12] Kuroki, H., Tokunaga, Y.: Int. J. of Powd. Metall. and Powd. Tech., vol. 20, 1984, p. 163
[13] T. Wada: Trans. of National Research Inst. for Metals, vol. 6, 1964, p. 153