The Effect of Cooling Rate on the Structure and Mechanical Properties of Fe-3%Mn-(Cr)-(Mo)-C PM Steels

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Abstract

The effect of different cooling rate on the structure and mechanical properties of Fe-3%Mn-(Cr)-(Mo)-0.3%C steels is described. Pre-alloyed Astaloy CrM and CrL, ferromanganese and graphite were used as the starting powders. Following pressing in a rigid die, compacts were sintered at 1120℃ and 1250℃ in H_2/N_2 atmospheres and cooled with cooling rates 1.4℃/min and 65℃/min. Convecitve cooled specimens were subsequently tempered at 200℃ for 60 and 240 minutes.

Keywords : PM steels, mechanical properties, cooling rate, slow and convective cooling, sinter-hardening effect

1. Introduction

The present trend in PM structural steels is to increase their alloy content to obtain high strengths without any heat treatment. As a result, increasing amount of bainite and/or martensite in the structure can be expected in the parts made from such steels [1,2]. Very slow furnace cooling favoured plasticity, which ceased to be significant for cooling rate 1.4°Cmin^{-1} [3]. When specimens cooled at 65°Cmin^{-1} were tempered at 200°C, the improvement in properties was attained. The as-sintered specimens show low impact resistance but tempering at 200°C transforms tetragonal martensite to a hexagonal ε-carbide, plus low-carbon martensite, which lowers internal stresses [4]. In fact some PM steels are already being used in the fully bainitic/martensitic condition [5]. It becomes necessary to determine the factors underlying the strengthening of the bainitic structures and to evaluate the possibilities of influencing the intrinsic properties of these structures though modifications in composition or thermal treatment [6].

2. Experimental Procedure

The steels based on Astaloy CrL and CrM powders were produced and examined. 3% of Mn in the form of low-carbon ferromanganese and 0.3% graphite was added to powders mixtures. Mixtures of powders were cold compacted to prepare 55x10x5 mm TRS and ISO 2740 UTS test bars (green density - 6.82-7.14 gcm^{-3}). Sintering was carried out in H_2/N_2 atmospheres at 1120°C and 1250°C for 60 minutes, employing slow (1.4 °Cmin^{-1}) [4] and convective (65°Cmin^{-1}) rates. The as-sintered and as-tempered densities (tempering at 200°C/60 and 240 minutes) were varied from 6.84-7.18 gcm^{-3}.

3. Results

The investigation resulted in the identification of microstructures as having been produced in the pearlitic and bainitic zone on furnace as well as continuous cooling. Pearlitic structure forms on cooling at lower rates than those giving bainitic structure, which is relatively acicular and much finer than pearlitic structure. This actually accounts for the improved bend and tensile properties observed (Table 1). Bainite in the investigated steels consisted of an aggregate of acicular ferrite and carbides. Its morphology changed with the transformation temperature - the size of the particles and the acicularity of the structure increased as the temperature decreased. In many cases we have been able to show the occurrence of structures that did not correspond to the accepted classical definition, in which fine bainite and Mn-rich retained austenite zones, partly transformed into martensite, is present. When austenitic-martensitic plates extend across the grains, the impact strength (IT) decreases sharply. Also a spectacular strength increase together with an appreciable decrease in impact strength is observed in most specimens when at the end of the bainitic transformation a certain amount of acicular martensite is formed inside the acicular-bainitic regions.

4. Summary

The problem of quantitatively correlating properties with microstructure is complex. In case of the presented work, in specimens cooled with cooling rate 65°Cmin^{-1}, the problem is complicated by the fact that simultaneously in the structure very fine pearlite, bainite, martensite and retained austenite are presented.

Table 1. Mechanical properties of the Astaloy CrL and CrM-base steels tempered at 200°C – bold for CrM.

Sint. atm.	Tempering time, min	UTS, MPa	$R_{0.2}$, MPa	A, %	TRS, MPa	IT, J/cm^2	HV_{30} surf.
sintering temperature - 1120°C							
H_2	0	545	ND	1.0	1171	6.04	198
		ND	**ND**	**ND**	**1041**	**4.59**	**389**
	60	554	481	0.8	1216	3.37	245
		439	**357**	**0.6**	**1195**	**5.82**	**305**
	240	625	553	0.6	1163	5.15	263
		687	**635**	**1.2**	**1096**	**5.47**	**291**
$75H_2$-$25N_2$	0	514	507	0.8	825	4.09	222
		447	**ND**	**0.7**	**702**	**3.00**	**206**
	60	439	ND	0.6	1017	3.04	262
		563	**ND**	**0.8**	**1030**	**3.33**	**268**
	240	662	457	1.1	1045	3.58	210
		535	**474**	**0.8**	**1230**	**3.51**	**310**
$25H_2$-$75N_2$	0	634	517	1.21	1003	4.11	342
		642	**537**	**1.1**	**689**	**5.48**	**400**
	60	662	608	1.0	1049	3.55	318
		645	**560**	**1.1**	**1105**	**4.95**	**317**
	240	608	554	0.9	1018	6.99	280
		575	**517**	**0.9**	**1035**	**4.03**	**309**
$5H_2$-$95N_2$	0	654	498	1.1	805	4.84	317
		416	**ND**	**0.5**	**828**	**4.05**	**372**
	60	542	481	0.8	1020	3.04	284
		648	**537**	**1.7**	**982**	**3.34**	**323**
	240	506	405	0.7	912	2.51	278
		621	**577**	**2.0**	**941**	**3.16**	**307**
N_2	0	495	450	0.8	765	4.26	315
		595	**492**	**1.9**	**399**	**2.47**	**395**
	60	541	481	0.8	1191	3.40	274
		706	**535**	**2.5**	**855**	**4.05**	**320**
	240	544	508	0.8	1082	3.39	298
		700	**587**	**2.5**	**1131**	**4.07**	**319**
sintering temperature - 1250°C							
H_2	0	573	410	1.1	1354	13.97	252
		858	**563**	**2.3**	**1349**	**7.85**	**314**
	60	604	474	1.2	1613	15.18	222
		811	**594**	**1.8**	**1543**	**6.55**	**302**
	240	630	543	1.2	1412	14.06	239
		813	**598**	**1.7**	**1463**	**5.82**	**282**
$75H_2$-$25N_2$	0	594	447	1.3	1214	11.35	253
		781	**521**	**1.6**	**1501**	**8.23**	**306**
	60	682	475	1.5	1549	10.93	244
		752	**632**	**1.3**	**1665**	**8.12**	**313**
	240	638	506	1.4	1358	10.66	251
		808	**601**	**1.7**	**1428**	**6.35**	**296**
$25H_2$-$75N_2$	0	622	505	1.2	1530	7.72	220
		886	**573**	**2.3**	**1610**	**7.85**	**331**
	60	753	537	1.6	1348	6.47	278
		905	**613**	**2.3**	**1695**	**6.88**	**304**
	240	791	557	1.7	1530	9.19	282
		811	**576**	**1.7**	**1598**	**10.09**	**329**
$5H_2$-$95N_2$	0	799	472	1.8	1519	5.23	296
		901	**604**	**2.2**	**1572**	**13.00**	**334**
	60	785	535	1.7	1407	5.96	273
		872	**615**	**2.2**	**1610**	**8.92**	**319**
	240	669	565	1.2	1169	6.31	268
		925	**595**	**2.8**	**1705**	**8.43**	**338**
N_2	0	822	554	2.2	1428	10.35	281
		802	**583**	**1.7**	**1675**	**14.07**	**328**
	60	829	554	2.0	1469	5.78	272
		954	**562**	**2.8**	**1658**	**10.71**	**315**
	240	813	596	1.7	1702	15.25	262
		965	**584**	**2.8**	**1527**	**7.98**	**327**

Many factors must be put forward to explain the investigated steels strength: inherent strength of bainite, solid solution hardening of the ferrite, obstacles placed by the austenitic-martensitic island, presence within the structure of an appreciable percentage of martensite resulting from partial transformation of the stabilised austenite and in th end the mechanical properties of bainitic structures. In the investigated steels a bainitic structure can be obtained by the direct quenching of austenite. This structure exhibits not only high UTS but also impact properties that approach those of tempered martensite. In these self-hardening steels it is practically impossible to obtain by continuous cooling a bainite with a structure similar to that of tempered martensite because of presence of acicular martensite.

5. References

1. A. Cias, Habilitation Thesis, AGH-UST, Cracow, 2004.
2. M. Youseffi, S.C. Mitchell, A.S. Wronski, and A. Cias: Powder Metall., **43[4],** 353(2000).
3. M. Sulowski, A. Cias, M. Stoytchev and T. Andreev: Mater. Sci. Forum, in press.
4. A. Cias, S. C. Mitchell: Powder Metall. Progress, **5**, 82(2005).
5. A. Cias: Powder Metall. Progress, **5[3]**, 147(2005).
6. A. Cias, S. C. Mitchell, A. Watts, A.S. Wronski, Powder Metall., **42[3]**, 227(1999).

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