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Improving the wear resistance of M41 steel by nitrogen alloying and ESR

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Abstract

AISI M41 high-speed steel (HSS) is considered as a super-hard tool steel due to high hardness level (65–70 HRC). Nitrogen alloying of AISI M41 HSS produces marked solid solution hardening and precipitation strengthening in addition to an improvement in pitting resistance. The mechanical properties in general, and wear resistance in particular, are strongly affected by the steel cleanliness and the status of non-metallic inclusions in steel. For this reason tool steel should be subjected to a secondary refining process. In this work, the wear characteristics of AISI M41 HSS were investigated. The effect of nitrogen alloying and electroslag refining (ESR) of this steel grade were considered. Both conventional and nitrogen alloyed grades were melted in open air induction furnaces and then remelted under three different compositions of calcium fluoride-based flux in an ESR machine. The wear behaviour of the resulting steels, for both conventional and nitrogen-alloyed grades before and after ESR, was monitored. The addition of nitrogen improves markedly the wear resistance of AISI M41 HSS. This improvement depends on the total nitrogen content and is independent on the form of the nitrogen constituent. The ESR process improves markedly the wear resistance of both conventional and nitrogen-alloyed grades.

Keywords: High-speed steel; Nitrogen; ESR; Wear; Hardness; Inclusions

1. Introduction

AISI M41 high-speed tool steel may be considered as a high-speed AISI M2 tool steel but with an addition of cobalt (5–10%). Increasing cobalt aids the crystallization of primary carbonitride phase colonies. The size and quantity of such colonies increase with increasing cobalt content because cobalt removes carbon and nitrogen from the solid solution, resulting in increasing the concentration of the carbonitrides. AISI M41 high-speed tool steel is also called a super-hard tool steel due to the high hardness level (65–70 HRC) [1,2].

Nitrogen is also known to produce some beneficial effects in steels and can therefore be regarded as a significant alloying element in ferrous materials. In addition to its role with aluminum as a grain refining agent, nitrogen produces marked solid solution hardening and precipitation strengthening reactions that form the basis of many high-strength grades. Nitrogen addition is particularly beneficial to the constitution and pitting resistance of austenitic stainless grades. Nitrogen alloying up to 0.18% to low cobalt-containing steels (Co ≈ 2 wt.%) leads to an increase of the secondary hardness and heat resistance to the level of S6-5-2-5

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Table 1
Chemical composition of consumable electrodes and produced ingots in ESR process

Steel grade	Process	ESR flux	Chemical composition (wt.%)										
			C	Si	Mn	Cr	Mo	Co	V	W	P	S	N
M41	IF		0.9168	0.4285	0.2923	4.08	4.2125	5.02	2.115	6.53	0.0207	0.0121	0.045
	ESR1	F1	0.948	0.4525	0.254	4.05	4.1275	4.99	1.995	6.288	0.0206	0.009	0.0082
	ESR2	F2	0.8588	0.345	0.287	3.733	3.8975	4.95	1.838	6.108	0.0208	0.0075	0.036
	ESR3	F3	0.92	0.421	0.287	3.975	4.13	5.0	2.058	6.463	0.0221	0.0053	0.031
M41N	IFN		0.90225	0.509	0.18	3.785	4.2	4.78	2.128	6.815	0.0226	0.0082	0.035
	ESRN1	F1	0.9285	0.501	0.176	3.658	4.0375	4.99	2.058	6.745	0.0228	0.0061	0.093
	ESRN2	F2	0.939	0.4893	0.178	3.52	4.0425	5.005	2.003	6.24	0.0229	0.008	0.1139
	ESRN3	F3	1.053	0.4935	0.201	3.615	4.1625	4.995	2.158	6.915	0.0244	0.0083	0.1167

IF = air melted induction furnace heat (free nitrogen). ESR1 = free electroslag remelting (free nitrogen) under slag no. 1. ESR2 = electroslag remelting (free nitrogen) under slag no. 2. ESR3 = electroslag remelting (free nitrogen) under slag no. 3. IFN = air melted induction furnace heat (nitrogen containing). ESRN1 = electroslag remelting (nitrogen containing) under slag no. 1. ESRN2 = electroslag remelting (nitrogen containing) under slag no. 2. ESRN3 = electroslag remelting (nitrogen containing) under slag no. 3.

steel with 5 wt.% Co (AISI M41). The magnitude of the secondary hardness and heat resistance of S6-5-2-5 and S6-5-2-10 high-cobalt steels cannot be substantially increased by nitrogen alloying. However, it was concluded that, by nitrogen alloying, it is possible to attain good mechanical properties with lower cobalt content steels [2].

The second component of cutting ability is resistance to wear. Cutting tools are subjected to high force under conditions of high temperature and wear [3,4]. The wear resistance is determined by the structure and properties of a tool steel and, to a large extent, by the properties of the material being machined. Other factors that have influence on the wear resistance of tool steel include the hardness, abrasion and corrosion effect, coefficient of friction, the temperature in the friction zone, mechanical effects, and erosion [3]. A change in a few of these factors can be accomplished by changing the composition, phase state and other properties of the tool steel. Among the external factors, those most important are the thermal factor and loading conditions; dynamic loads, specific baths (pressures) and also the role of corrosion in the matched pair. A higher surface hardness is an essential condition for obtaining higher wear resistance in most kinds of steel alloys. The best wear resistance is exhibited by material whose structure consists of a solid carbide phase retained in a high-strength matrix [5–8]. The wear rate decreases with an increase of volume fraction of carbide existing in the structure, regardless of the production process used [5].

In addition, electroslag refining (ESR) is an attractive and feasible secondary refining process due to its economy and powerful effect in decreasing the content of non-metallic inclusions (NMI), gases, sulfur and segregation in steel alloys [6,9,10]. Improving the cleanliness, soundness and homogeneity of steel results in improving its mechanical properties in general, and wear resistance in particular [3–6]. The present work aims to study the influence of nitrogen alloying and electroslag refining under CaF_2-based slag on the wear behaviour of AISI M41 high-speed tool steel.

2. Experimental work

To attain the goal of this study, AISI M41 high-speed tool steel was melted in open air induction furnace (IF) twice. The first steel alloy investigated was the standard AISI M41 high-speed steel. The second steel studied has been developed as a new grade of steel comparable to AISI M41 high-speed steel, but alloyed with nitrogen (denoted as M41N), as given in Table 1. Tool steel scrap was used in the charge and the losses in alloying elements were compensated for by using ferroalloys (Fe–Mn, Fe–W, Fe–Cr and Fe–V). In case of the nitrogen-alloyed steel grade, nitrovan (16% N and 84% V) was used instead of Fe–V. The molten steel was cast in the form of cylindrical ingots with a dimension of 75 mm diameter and 120 mm length.

Table 2
Chemical composition and physical properties of synthetic slag at 1600 °C

ESR flux	Chemical composition (wt.%)			CaO/Al_2O_3	Physical properties		
	CaF_2	CaO	Al_2O_3		Density (g/cm^3)	Viscosity poise	Interfacial tension (mN/m)
F1	65	15	20	0.75	2.555	0.433	1375
F2	75	15	10	1.5	2.55	0.225	1405
F3	55	30	15	2.0	2.53	0.3	1395