A. GIGOVIĆ-GEKIĆ, M. ORUČ, I. VITEZ, B. VUJIČIĆ

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ANALYSE AND RESEARCH OF NONMETALLIC INCLUSIONS FOR STEEL 100Cr6

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Steel 100Cr6 belongs to a group of hardened steels, which are applicable for production of rolling element parts. Because of specific working conditions, a proper chemical composition is required with a minimum content of nonmetallic inclusion. In this paper, the research results of presence the nonmetallic inclusions and their chemical composition are presented for the steel produced in vacuum and open induction electric furnace and their influence on the prescribed properties for this steel. The optical and scanning electronic microscope are used to identify presence and the chemical compositions of nonmetallic inclusions.

Key words: steel 100Cr6, nonmetallic inclusions, optical and scanning electronic microscope, vacuum and induction electric furnace

Analiza i ispitivanje nemetalnih uključaka za čelik 100Cr6. Čelik 100Cr6 pripada grupi prokaljivih čelika koji su prvenstveno našli primjenu u proizvodnji dijelova kotrljajućih ležajeva. Glede posebnih uvjeta rada za ovu vrstu čelika se zahtijeva propisani kemijski sastav sa minimalnim prisustvom nemetalnih uključaka. U ovom radu su predstavljeni rezultati ispitivanja prisustva nemetalnih uključaka i njihov kemijski sastav za čelik 100Cr6 proizveden u vakuumskoj i otvorenoj indukcionoj elektro peći te njihov uticaj na svojstva propisane normom za ovu vrstu čelika. Ispitivanje prisustva nemetalnih uključaka kao i analiza kemijskog sastava urađena je primjenom optičkog i skening elektronskog mikroskopa.

Ključne riječi: čelik 100Cr6, nemetalni uključci, optički i skening elektronski mikroskop, vakuumska i indukcijska elektro peć

INTRODUCTION

The steel 100Cr6 is mainly used for production of rolling element parts like balls, cylinders and rings for bearings having a diameter up to 30 mm. The bearings are used as machine parts that are stressed by reversed compression, tension and shear loads during an exploitation [1, 2]. The presence of nonmetallic inclusions plays very important role in determination of the material properties, especially when aim is improvement of the mechanical properties. Investigation of the nonmetallic inclusions influence on a steel quality is based on their dimension, shape, chemical and mineralogical composition and physical characteristic (melting temperature, deformability, hardness etc.). Above mentioned nonmetallic inclusions properties mainly depend on way of production and casting of steel and they can vary from charge to charge. In order to extend the working life of bearings the following is necessary: high and uniformly spaced hardness, wear resistance, fatigue resistance, high strength and elasticity and good machinability. Accordingly, the smallest defects in the materials like inclusions or different microstructure have harmfull effects on properties and exploitation of the steel [1, 2, 3, 4].

EXSPERIMENTAL PROCEDURE

A plan of experimental work was carried out as follows:

– production of steel 100Cr6
– plastic processing
– heat treatment
– metalographical investigation.

PRODUCTION OF STEEL 100Cr6

Experimental melts of 100Cr6 steel are produced in open and vacuum induction electrical furnaces at Metallurgical Institute „Kemal Kapetanović“ in Zenica. A steel scrap (bars and sheets) was used as a raw material in open induction electrical furnace. Raw materials prepared in open induction furnace were used as a charge for the vacuum induction electrical furnace. The chemical composition of produced samples is given in Figure 1.

A. Gigović-Gekić, University of Zenica, Faculty of Metallurgy and Materials Science, Zenica, BiH
M. Oruč, Metallurgical Institute “Kemal Kapetanović”, Zenica, BiH
I. Vitez, University of Osijek, Faculty of Mechanical Engineering, Slavonski Brod, Croatia
B. Vujičić, University of Osijek, Polytehnic, Slavonski Brod, Croatia

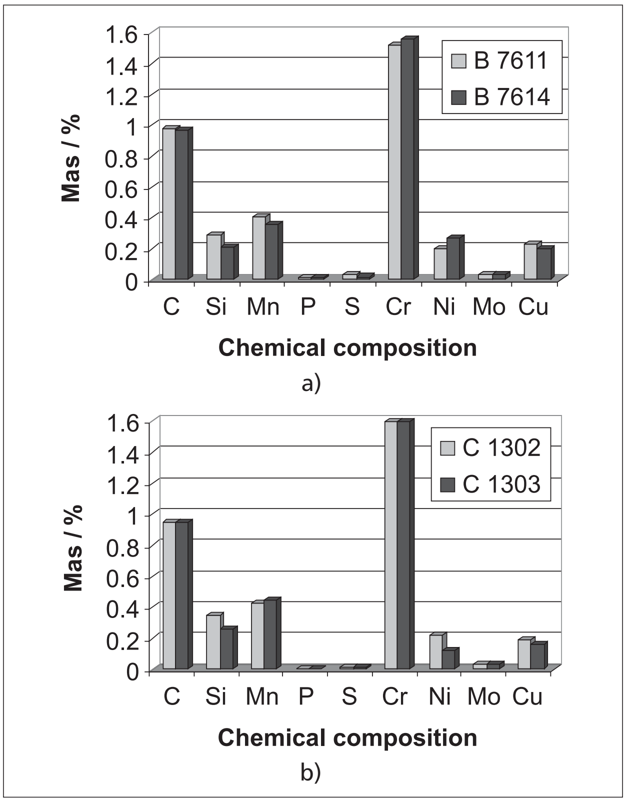


Figure 1. Chemical compositions of 100Cr6 steel produced in open induction furnace a) and vacuum induction furnace b)

PLASTIC PROCESSING

- Plastic processing by hammering (with dimension 120x120 mm on 34 x 34 mm)
- Rolling with dimension 34 x 34 mm on ø 26 mm.

Heat treatment

The samples of the steel 100Cr6 are heat treated as follows:

- heating to a temperature 800 °C in the furnace without protection atmosphere
- holding at that temperature for about 4 hours
- cooling in the furnace
- heating to a temperature 820 °C in the furnace without protection atmosphere
- holding at that temperature for about 20 minutes
- quenching in water
- heating to a temperature 180 °C in the furnace without protection atmosphere
- holding at that temperature for about 1 hour and 30 minutes
- cooling.

Metalographical investigation

After heat treatment, an optical microscope was used for investigating and identification of nonmetallic inclusions. The analyse of chemical compostions observed nonmetallic inclusion was done by a scanning electronic microscope.

RESULTS AND DISCUSION

Chemical analyse

The achieved and prescribed chemical composition according to standards ASTM A 295/94 and DIN 17230/80 for 100Cr6 steel is given in Table 1 [5, 6].

Table 1. **Chemical composition**

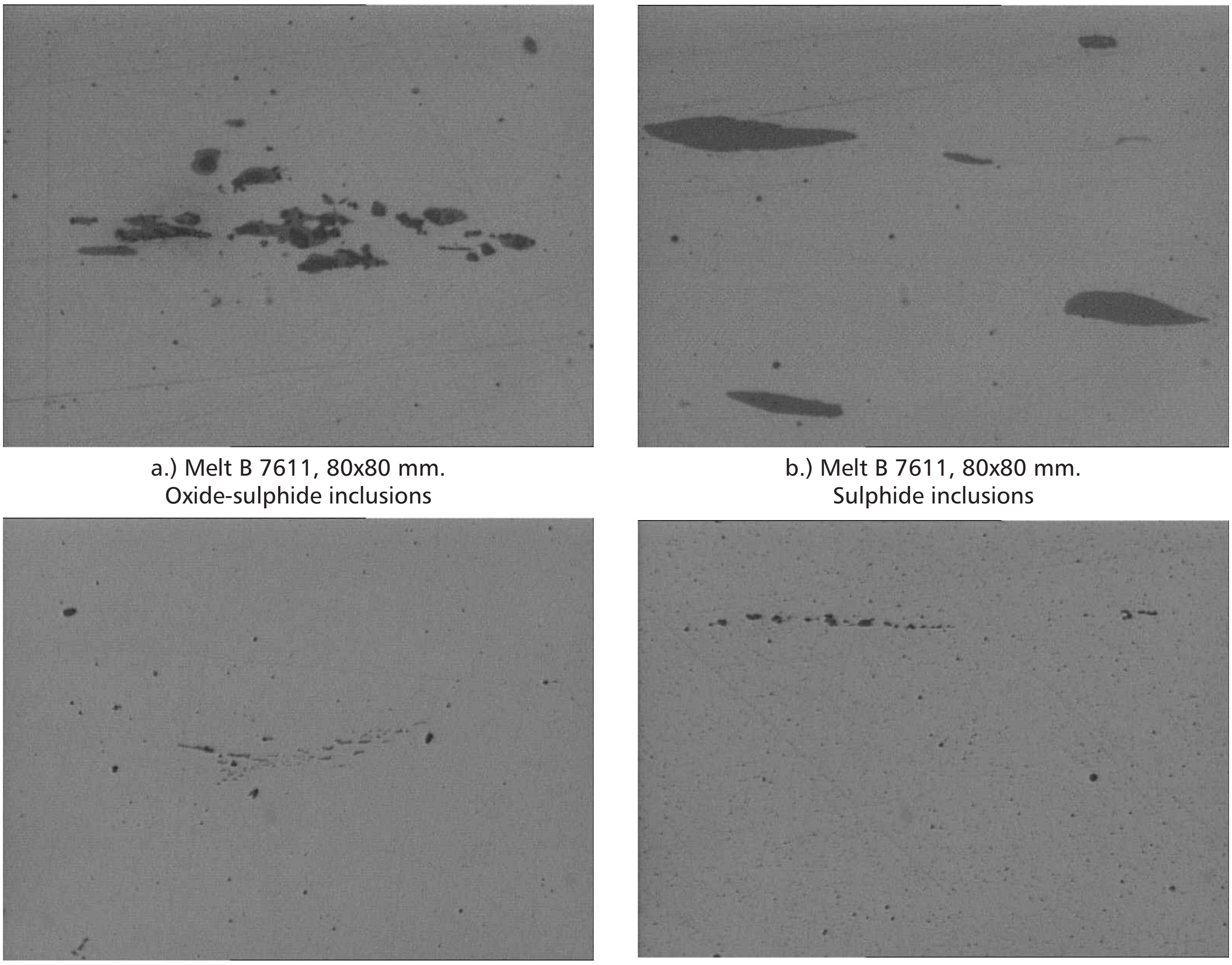
Element / %	ASTM A 295/94	DIN 17230/80	B 7611	C 1302
C	0,98/1,10	0,9/1,05	0,98	0,95
Si	0,15/0,35	0,15/0,35	0,29	0,35
Mn	0,25/0,45	0,25/0,45	0,41	0,43
P	max.0,025	max.0,030	0,013	0,007
S	max.0,025	max.0,025	0,029	0,016
Cr	1,30/1,60	1,35/1,65	1,52	1,60
Ni	max.0,25	max.0,30	0,20	0,22
Mo	max. 0,10	-	0,03	0,03
Cu	max.0,35	max.0,30	0,23	0,19

Analyse of non-metallic inclusions by the optical microscope

A results of the analyse of nonmetallic inclusions were done according to standard ASTM E 45, method A, the worst field [7]. The samples were tested in quenched and tempered state. The metallographic analyse shows a presence of oxide, oxide-sulphide, aluminates and sulphide inclusions in all melts, Figure 2. Increasing of the deformation degree during the plastic processing increases deformation of observed the sulphides. After the plastic processing new arrange of the sulphide inclusions was observed forming strings. The sulphide inclusions in the vacuum melts are more plastic because they are pure sulphides in comparing with the oxide-sulphide inclusions in the case from the open induction furnace. The presence of silicates is not noticed. The nonmetallic inclusions are distributed by primary grain border and grouped in small nest by lower deformation degrees and they are arranged forming strings in case of higher deformation degrees.

Analyse of non-metallic inclusions by the scanning electronic microscope

As addition to the analyse of nonmetallic inclusions by optical microscope, the investigation of presence and chemical composition of nonmetallic inclusions was done at the Institute for materials and technology in Ljubljana-Slovenia. The samples in annealing state of



a.) Melt B 7611, 80x80 mm. Oxide-sulphide inclusions

b.) Melt B 7611, 80x80 mm. Sulphide inclusions

c.) Melt C1302, 80x80 mm. Sulphide inclusions

d.) Melt C1302, 34 x34 mm. Aluminates inclusions

Figure 2. Distribution of presented nonmetallic inclusions for steel 100Cr6, 50x

100Cr6 steel from both types of melts were investigated. The chemical composition and the inclusions shape for the melts from the open induction furnace are given in Figure 3.

The chemical composition and the inclusions shape for the melts from the vacuum induction furnace are given in Figure 4.

The analyse of nonmetallic inclusions by the scanning electronic microscope indicated a presence of Al_2O_3, MnS, (FeMn)S inclusions and rarely TiN inclusions. It is possible to see a characteristic shape for some sort of inclusions by different magnification, described in a literature [8, 9]. The oxide inclusions Al_2O_3 are spherical in shape, TiN inclusions have irregular shape and sharp edges and MnS inclusions have deformed shape. The analyse of chemical composition indicated a presence of (FeMn)S inclusions but they are visible only by higher magnification.

Determination of JK inclusion rating

JK inclusion rating is presented in Table 2. for steel 100Cr6.

Table 2. **JK inclusion rating (A-sulfide, B-aluminate, C-silicate, D-globular oxide)**

Inclusions	Melt	Thin series		Heavy series	
		Achieved	JK	Achieved	JK
A	B7611	1½-2	2 ½	1½-2½	1½
	C1302	1½-2		1-2	
B	B7611	½-2	2	1-2½	1
	C1302	1-2		1-2	
C	B7611	-	½	-	½
	C1302	-		-	
D	B7611	½-1	1	½-1	1
	C1302	1		1	

CONCLUSIONS

– From the chemical analysis of produced steel we can see the higher content of sulphur according to the standard ASTM 295 in the melts produced in the open induction electrical furnace. The higher content of sulphur in the raw materials is reason for that and if we want to reduce it the proper selection of raw materials is necessary.

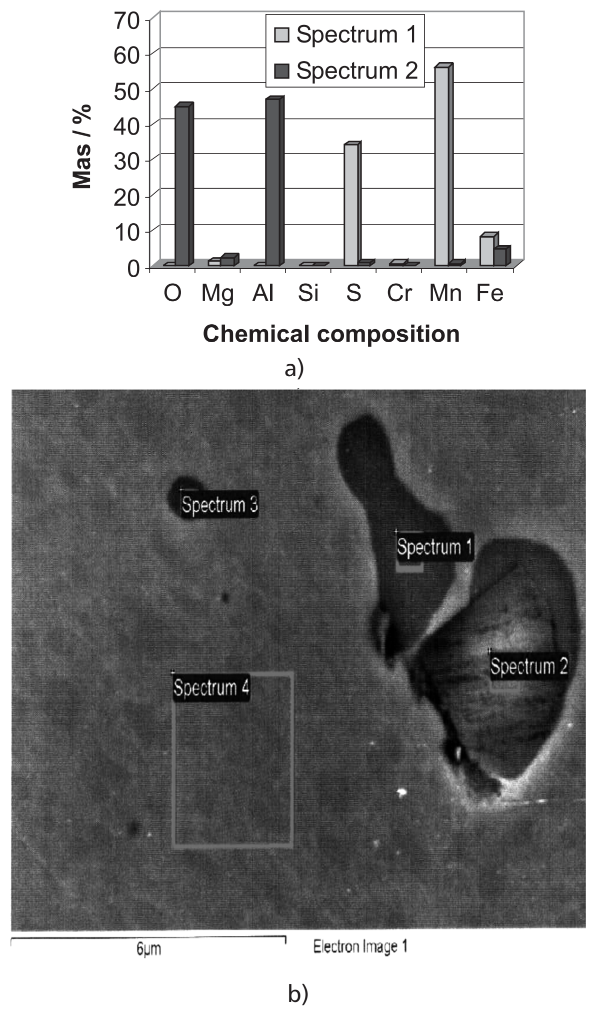


Figure 3. Chemical compositions a) and shape b) of representative sample inclusions 84-5 (Melt B 7611)-1, 9500x

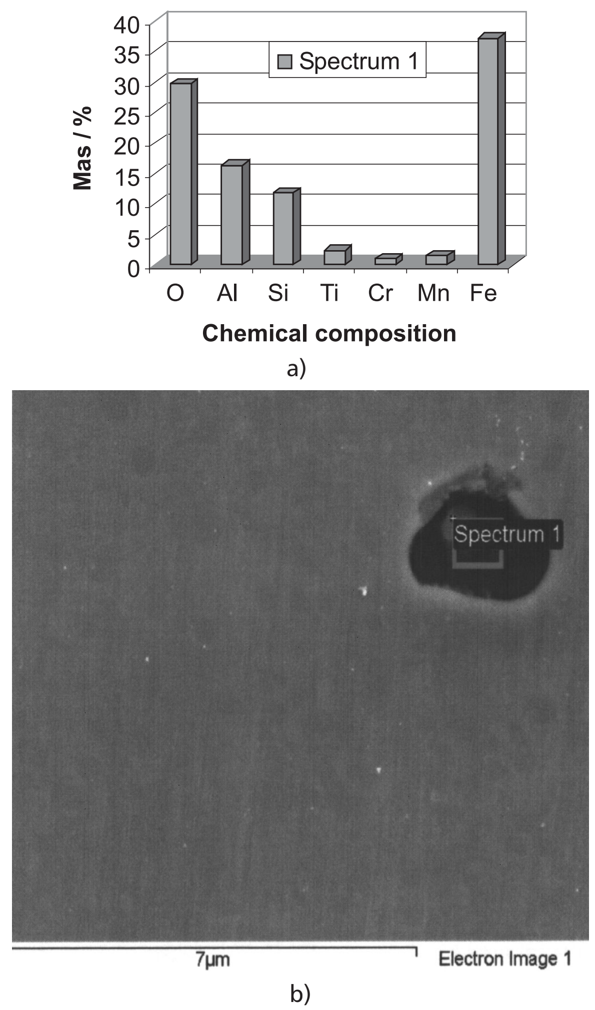


Figure 4. Chemical composition a) and shape b) of representative sample inclusions 144-5 (Melt C 1302)-2, 8500x

- Higher content of the sulphide inclusions in the melts is a result of increased level of sulphur. There is the increased content of oxides in the melt from open induction furnace, what was expected because the influence of atmosphere. The SEM analyse indicated a presence of the complex oxide-sulphide and sulphide nonmetallic inclusions. Harmfully effects of inclusions is reduced by increasing the deformation degree.
- The proper selection of raw materials is very important and vacuum furnace should be used for melting, in the case of the industrial production higher grades of bearing steel [10, 11].
- It is necessary to investigated as next step, open induction furnace can be used for production of some grades of bearing steels and selection of raw materials what is very important too [12].

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Note: English language lecturer: Dijana Hasanica, Zenica, Bosnia and Herzegovina