ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 4/2008

209 – 212

39/4

Effect of inoculation on high temperature plastic properties of the centrifugally cast Cr-Ni-Nb steel

G. Tęcza* J. Głownia
Department of Cast Alloys and Composites Engineering, Faculty of Foundry Engineering AGH,
Reymonta St. 23, 30-059 Cracow, Poland
*Corresponding author. E-mail address: sumik@interia.pl

Received 26.06.2008; accepted in revised form 14.07.2008

Abstract

From the centrifugally cast sleeve segments, in direction parallel to the axis, the specimens for mechanical tests were cut out in a way such as to get in one batch of the specimens a structure composed of columnar crystals and in another batch of the specimens a structure composed of equiaxial crystals. The specimens were subjected to a tensile test at the temperature of 820°C. It has been observed that the two zones of crystals differ quite considerably in the values of elongation, while preserving similar tensile strength levels.

Keywords: High-temperature mechanical properties, Austenitic Cr-Ni-Nb cast steel, Centrifugal casting, Columnar and equiaxial structure

1. Introduction

The development of chemical and petrochemical industries as well as permanent efforts to improve the efficiency of technological processes impose always more stringent requirements on materials assigned for various installations. Therefore, various attempts are made to develop materials that will be characterised not only by high chemical resistance but also by high creep resistance. To achieve this purpose, either new materials are sought, or the existing ones are modified and improved to satisfy the current requirements. Pipes that constitute the main element of catalytic and reforming furnaces have the length of up to 15 metres, the outside diameter of up to 160 mm, and the wall thickness of 12÷20 mm. These pipes are welded from segments up to 4 metres long, each of the segments being made by a centrifugal casting process. One single furnace can hold up to 400 pieces of the vertically placed segments of 15 metre length, the fact that quite well illustrates the demand for materials of this type. Over the past few decades, the chemical composition of alloys used for these pipes has changed many times as well as the technique by which they are made. This means that the properties of pipes must have been changing, too. At first, the pipes were hot rolled from low-carbon steels of the 20÷25Cr–20÷35Ni type, but low creep resistance of this material decided that soon they were replaced with pipes centrifugally cast from steels of higher carbon content and with an addition of Nb (alloys of the 2nd generation). To improve further their properties, nickel content was raised up to as much as 35÷40% and strong carbide-forming elements, like W, Co, or Mo, were introduced. The addition of strong carbide-forming elements improved the stability of carbides during long-lasting periods of service, raising additionally the resistance to the effect of chemically active environments. At present, alloys of the 4th generation, besides the Nb and Ti inoculants introduced previously, are enriched with additions of microelements like Zr and rare earth metals, often added in the form of mischmetal. Of all the examined alloys, the highest creep resistance offer those included in the last group, and this is due mainly to the high

stability of carbides hardening the alloy. The coarse grain structure of austenite in the centrifugally cast pipes along with carbide precipitates confer to the cast steel high creep resistance at the temperature of 950°C [1÷6].
Numerous studies have been devoted to the problem of the type and number of inoculants used currently, but literature rarely mentions the problem of modification of the chemical composition with V, and therefore some attempts have been made to centrifugally cast pipe segments from the Cr25-Ni32-Nb steel inoculated with Ti, Zr and V, and to deterrmine their mechanical and plastic properties at service temperatures.

2. Methods investigation

The cast steel chemical composition was adjusted so as to make it correspond to the Cr25-Ni32-Nb grade, commonly used for cast pipes. In own investigations, a modification of the chemical composition was planned by introducing to the alloy various combinations of Ti, Zr and V. As a test material, segments of the sleeves, previously cast in laboratory by the centrifugal process, were used. The chemical composition is given in Table 1.
Since catalytic pipes are made by the process of centrifugal casting, the external layer of these pipes has the structure composed of columnar crystals, while the internal layer has the structure of equiaxial crystals. The properties of both these zones differ considerably and have an important influence on alloy behaviour at service temperatures.

Table 1.
Chemical composition of the examined cast steel

Cast steel designation	Chemical composition [wt.%]											
	C	**Si**	**Mn**	**Cr**	**Ni**	**Nb**	**Ti**	**Zr**	**V**	**P**	**S**	**Mo**
11(niemodyfikowany)	0,29	1,99	1,06	24,99	30,82	1,16	–	–	–	0,016	0,012	0,17
66 (2xTi+Zr+V)	0,31	3,11	0,66	23,00	28,60	1,41	**0,23**	**0,082**	**0,11**	0,014	0,041	0,30
77 (Ti+2xZr+V)	0,29	3,20	0,60	24,00	29,60	1,45	**0,14**	**0,155**	**0,10**	0,035	0,019	0,29
88 (2xTi+Zr+2xV)	0,26	2,92	0,60	23,70	28,70	1,55	**0,25**	**0,082**	**0,24**	0,036	0,020	0,28

From the cast sleeve segments, parallel to their axis, the specimens for mechanical tests were cut out according to a schematic representation presented in Figure 1.

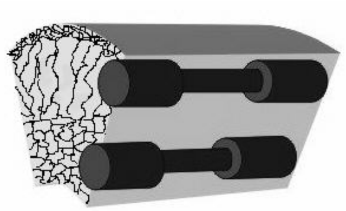

Fig. 1. Schematic diagram of cutting out specimens for testing of mechanical and plastic properties

The specimens were prepared in a way such as to have in those cut out from the external surfaces the structure composed of columnar crystals, and in those cut out from the internal surface the structure composed of equiaxial crystals. The microstructure was examined on thin slices taken from the specimen heads in direction normal to their axis (Fig. 2).

Fig. 2. Schematic diagram of cutting out specimens for structure examinations

After mechanical polishing with alumina to better disclose the microstructure, the ready planes were etched with a solution of HCl + HNO_3 + glycerine. Thus obtained microstructures were examined under an optical NEOPHOT 32 microscope at a magnification of 200x. The choice of specimens for mechanical tests was based on the results of investigations carried out previously by B. Mikułowski and J. Głownia, and on the results of own investigations. Circular specimens of a measuring length l = 25 mm and a measuring diameter d = 3 mm were prepared. A specimen for mechanical tests is shown in Figure 3.

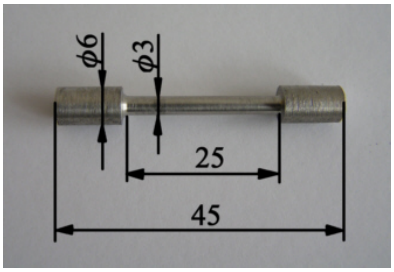

Fig. 3. Example of specimen for mechanical tests

Testing of mechanical properties was done at the temperature of 820°C. The choice of the test temperature was dictated by the conditions under which the tested grade of cast steel was expected to operate. In industrial furnaces, the surface of the catalytic pipes is heated up with burners to a temperature of 950 °C. Through their interior a chemically active medium is flowing at a pressure of up to 40 atmospheres, which means that inside the pipe an average temperature amounts to about 820 °C [1÷7]. Tensile tests were carried out on a universal Instron 1115 machine with electronic measuring system recording the values of forces acting on the specimen and the increase in length caused by these forces.

The machine is adjusted to tests made at high temperatures and is equipped with a heating element of special design and a stability of ± 5 °C. Tests were carried out at a tensile rate of ε = 1mm·min^{-1}. From the tensile test, the σ = f(ε) curves were plotted. The curves plotted for the columnar and equiaxial structures obtained in the examined alloys were compared with each other.

3. Results and discussion

Basing on the analysis of microstructures produced in specimens tested for the mechanical properties it has been observed that specimens cut out from the external surfaces were characterised by a columnar structure, while those taken from the internal surfaces had an equiaxial structure. Figure 4 shows examples of microstructures obtained in specimens tested for the mechanical properties.

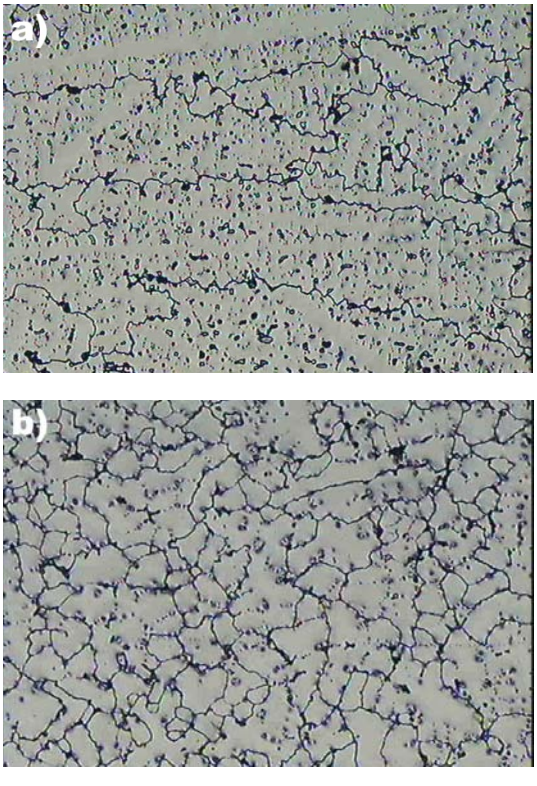

Fig. 4. Examples of microstructures obtained in specimens of the non-inoculated alloy tested for mechanical properties; specimens cut out from the external surface – columnar structure a), and specimens cut out from the internal surface – equiaxial structure b), etched with $HCl+HNO_3$+glycerine, magn. 200x

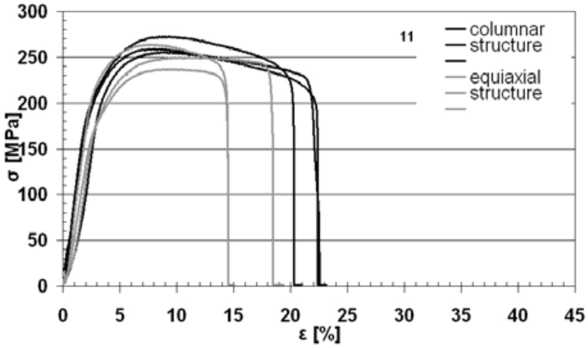

Fig. 5. Tensile curves for alloy 11 (non-inoculated), test temp. 820°C

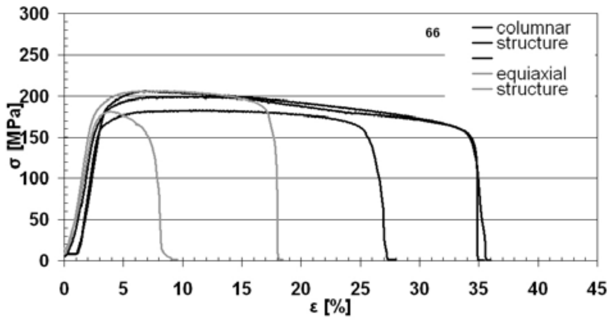

Fig. 6. Tensile curves for alloy 66 (inoculated with 2xTi+Zr+V), test temp. 820°C

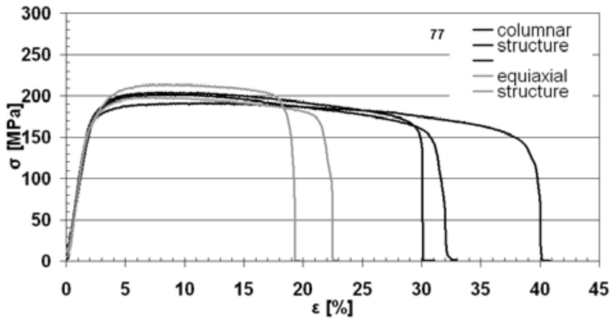

Fig. 7. Tensile curves for alloy 77 (inoculated with Ti+2xZr+V), test temp. 820°C

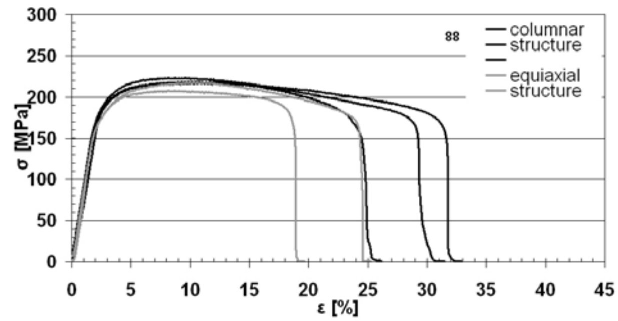

Fig. 8. Tensile curves for alloy 88 (inoculated with 2xTi+Zr+2xV), test temp. 820°C

Introducing Ti, Zr and V to the examined alloys brings a slight drop only in the tensile strength. The differences amount to about 50 MPa for the zone of columnar and equiaxial crystals. On the other hand, the differences in the values of elongation are much more significant. While in base alloy the values of elongation are similar for both zones, adding of inoculant makes these differences much more prominent.
Adding to the alloy a large amount of Ti (2xTi, alloy 66), or a large amount of Zr (2xZr, alloy 77) at a stable content of V raises the value of elongation in the zone of columnar crystals up to about 35%. Introducing large amounts of V to the alloy (2xV, alloy 88) arrests the growth of elongation. For this alloy the value of elongation amounts to about 30%. In all the examined alloys, in the zone of equiaxial crystals, the changes in elongation are not so important.

4. Conclusions

From the studies carried out so far the following conclusions follow:

1. Adding of inoculants to the alloy makes both zones of crystals differ in elongation, while the values of tensile strength remain similar.
2. The greatest growth of elongation in the zone of columnar crystals has been observed in alloys inoculated with Ti and Zr, and with the content of V kept at a low level.
3. In catalytic pipes much more recommended are the columnar structures, as they can offer high plastic deformations, and hence better stress relaxation capability.

Acknowledgements

The study was done under a research project No. N507 188 32/2810.

References

[1] Z. Bojarski i in., Exploitation problems of steam reformer catalytic tubes, Praca naukowa Uniwersytetu Śląskiego nr 266, Ed. of the Silesian University (1978) (in Polish).

[2] J. Łabanowski, Examination of degradation process of catalytic tubes during exploitation in reformer methane, Wydawnictwo Politechniki Gdańskiej, Gdańsk (2003) (in Polish).

[3] J. Barcik, Alloys on tubes. Chemical compositions; structure and exploitation properties. Ed. of the Silesian University, Katowice (1995).

[4] R. Zapała, J. Głownia, W. Ratuszek, G. Tęcza, Microstructural investigations of Cr-Ni-Nb cast steel with microelements used as tubes for petrochemical installations. Polska Metalurgia w latach 2002-2006, Wydawnictwo Naukowe Akapit, Kraków 2006, 431-436.

[5] M. Garbniak, B. Piekarski, Microstructure of as-cast austenitic cast steel type G-X30NiCrSi30.18 with additions of Nb and Ti. Proc. Int. Conf. EUROMAT'94, Hungary (1994), 555-559.

[6] G. Tęcza, J. Głownia, G. Boczkal, R. Zapała, Yield strenght and structural characterization of Cr25-Ni32-Nb steel modified by Ti, Zr, Ce and cast by centrifugal method. Polska Metalurgia w latach 2002-2006, Wydawnictwo Naukowe Akapit, Kraków 2006, 329-334 (in Polish).