EXPERIMENTAL STUDY OF THE SURFACE PROPERTIES OF SELECTED STEELS

ŘEHÁČKOVÁ Lenka[1, 2], ROSYPALOVÁ Silvie[1], DUDEK Rostislav[1, 2], SMETANA Bedřich[1, 2], ZLÁ Simona[1, 2], DOBROVSKÁ Jana[1, 2]

[1]*Faculty of Metallurgy and Materials Engineering, VSB - Technical University of Ostrava, Czech Republic, EU, lenka.rehackova@vsb.cz*

[2]*Regional material science and technology centre, VSB - Technical University of Ostrava, Czech Republic, EU*

Abstract

The surface tension of selected real steel grades and their wetting with alumina substrate in the temperature interval from the melting point to the temperature of 1600 °C were determined using the sessile drop technique. The effect of the major elements (carbon and chromium) on the surface properties of given steels was studied. Carbon and chromium contents were varied in the range of 0.077 - 0.411 wt. % and 0.046 -12.392 wt. %, respectively. It was shown that with an increasing content of both aforementioned components increased the surface tension of the investigated steels. The temperature dependencies of surface tension exhibit a steeper decrease at higher chromium contents.The contact angle of liquid steels with alumina substrate increased with increasing chromium content in the samples.

Keywords: Sessile drop method, surface tension, wetting angle, steels

1. INTRODUCTION

Surface tension is an important quantity from a physical and technological point of view in the steelmaking. To surface phenomena in steel production is closely related to coagulation and coalescence of non-metallic inclusions, the formation of gas bubbles, erosion and corrosion of refractory ceramics by molten steel, phenomena during crystallization of steel etc. The knowledge of temperature dependence of surface tension is crucial, because it drives Marangoni convection.

It is important to note that experimental study of surface tension of liquid multicomponent metallic alloy is very difficult, mainly because of the high reactivity of metallic melts at high temperature as well as due to extreme sensitivity of surface tension to impurities [1].

High - temperature wettability of the ceramic material by the liquid steel is a very important parameter for the assessment of their mutual interaction, e.g. during the casting process. Unfortunately, at very high temperatures during casting of steels the wettability of ceramic materials changes due to many factors (roughness of the substrate surface, chemical heterogeneity of the ceramic material, its porosity, chemical composition, reactivity of the molten metal).

Although, influence of carbon and chromium on surface tension of steel was investigated by many authors, the results of these studies are very different. Kawai et al. [2] reported that carbon acted as a surface active element. In contrast, Morohoshi et al. [3] reported that carbon itself has no influence on the surface tension, but reduces oxygen activity in the melt, which causes increase in the surface tension. Lee and Morita [4] reported that carbon increases the sulphur activity causing decrease in the surface tension, whereas at the same time carbon itself increases the surface tension. Jimbo and Cramb [5] reported that carbon causes small increase in the surface tension of liquid iron. Authors Li and Mukai [6, 7] determined the influence of chromium on surface tension, and reported a small rise in surface tension with small additions of chromium. The reason for the different behaviors among the previous studies is not clearly understood yet. But some discrepancy of the surface tension between investigators can be cause by varying concentrations of oxygen and sulphur in the samples or inaccurate experimental techniques. It is generally known, that oxygen and sulphur are strong surface active elements and therefor decrease surface tension of steel.

The presented work is focused on experimental studies of the temperature dependencies of wetting angles and surface tension of selected real steels, with various concentrations of carbon and chromium. The values of given quantities have been determined using the sessile drop technique.

2. EXPERIMENTAL RESEARCH

2.1. Materials

Five real steel grades (samples 1 - 5) were used for experimental measurement of surface properties, the chemical composition of which is shown in **Table 1**. The high purity Al_2O_3 (99.8 %) plate (37.3 x 44.7 x 2.0 mm) was used as a substrate in this study.

Table 1 Chemical composition of the steels (wt. %)

Sample	C	Cr	Mn	Si	P	S	Cu	Ni	Mo	Al	N	O
1	0.077	0.049	0.635	0.201	0.021	0.008	0.064	0.027	0.003	0.026	0.004	0.002
2	0.290	0.610	0.813	0.209	0.013	0.007	0.064	0.028	0.170	0.022	0.004	0.002
3	0.318	1.539	0.460	0.270	0.008	0.001	0.100	0.887	0.194	0.820	0.002	0.001
4	0.381	4.990	0.380	0.940	0.008	0.001	0.090	0.264	1.160	0.025	0.0068	0.001
5	0.411	12.392	0.344	0.375	0.016	0.011	-	0.218	0.027	-	-	0.001

Contents of other elements present in given steels are the following: < 0.003 Ti, < 0.003 Nb, < 0.0005 B, the rest is iron.

2.2. Preparation of samples

From given steels were prepared the cylindrical pieces (diameter 5 mm x height 5 mm), each weighing about 0.7 g. The steel pieces were mechanically polished to remove any surface oxide and cleaned with acetone. The Al_2O_3 plate was annealed at the temperature of 1200 °C and its surface immediately before experiment was cleaned with acetone, dried and used without touching the surfaces, in order to avoid any possible contamination. After the steel sample was set on the upper surface of the Al_2O_3 substrate and prepared for experiment.

2.3. Measurement of surface properties

Experimental measurement of surface properties (wetting angles, surface tension) was performed in a resistance observation furnace Clasic (**Figure 1**) in the temperature interval from the melting point of given steel sample to the temperature of 1600 °C by the sessile drop method. This method is based on automatic recognition of geometric shape of a drop, which is sessile on a non-wettable plate [8]. Alumina plate was used as a non-wettable plate for investigated steels. Recognition of the drop shape is divided into two steps. Firstly, the approximate height of the drop in the image is estimated and secondly, the contour segments of the drop are found. The Laplace - Young equation is used for evaluation of the image.

Prepared sample was settled at the centre of the furnace to thermocouple, the reaction chamber was sealed and evacuated and then purified argon gas (> 99.9999 %). Then the system was heated to the temperature of 1600 °C at the heating rate 5 °C / min. The temperature was measured by the thermocouple Pt - 13%Rh/Pt. When the sample was melted, the shape of sessile drop was monitored by the camera CANON

EOS 550D. The images of drop (**Figure 2**) were recorded only during the heating. The experiment was performed under an inert atmosphere of argon in order to avoid the oxidation of sample.

Figure 1 Resistant furnace Clasic

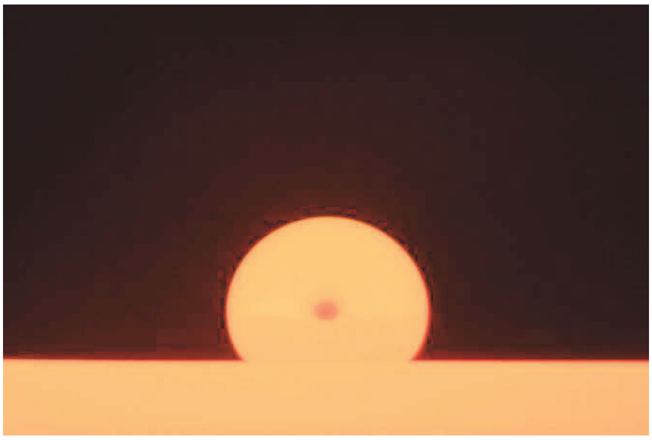


Figure 2 Image of real sessile drop

3. RESULTS AND DISCUSSION

The temperature dependencies of the surface tension of the steel samples in the temperature interval from their melting point to the temperature of 1600 °C are shown in **Figure 3**.

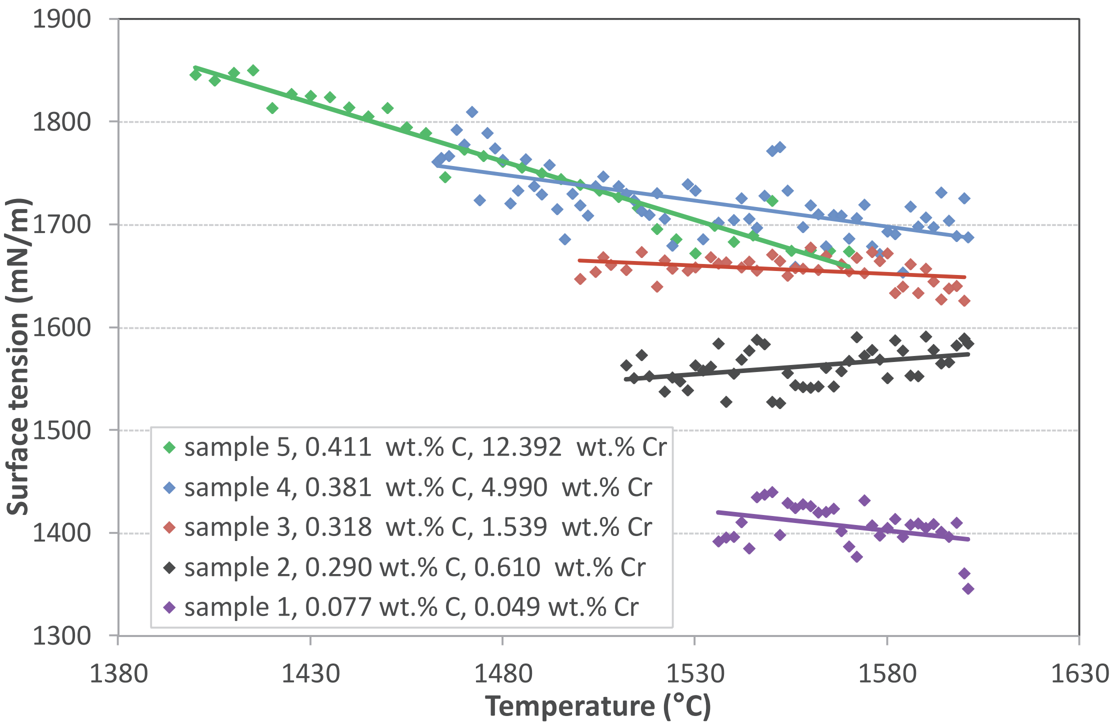


Figure 3 Temperature dependencies of the surface tension of investigated steels

From this Figure it is evident that the surface tension, with the exception of sample 2, decreases with increasing temperature. The surface tension of sample 2 increases very slightly with increasing temperature. The temperature dependencies of surface tension exhibit a steeper decrease at higher chromium contents, this is particularly apparent for the sample 5 with chromium content 12.392 wt. %.

Increasing content of carbon and chromium acts on the steel surface tension positive, this means that with increasing content of the aforementioned elements the surface tension increases, see in **Figure 3**. However, the surface tension of investigated steels can be affected by the presence of surface active elements such as oxygen and sulphur, which were present in the steels already before the experiment. It is possible therefore lean towards the opinions of the authors [3, 4, 9] that the effect of carbon and chromium is greatly influenced by the presence of surface active elements. Carbon itself has no influence on the surface tension, but reduces oxygen activity in the melt, which causes increase in the surface tension. Carbon may also increase the sulphur activity causing decrease in the surface tension, whereas at the same time carbon itself increases the surface tension. The presence of oxygen also influences the effect of chromium on the surface tension. Chromium has a relatively strong affinity to oxygen; one can therefore reduce the oxygen activity in the melt and consequently increase the surface tension.

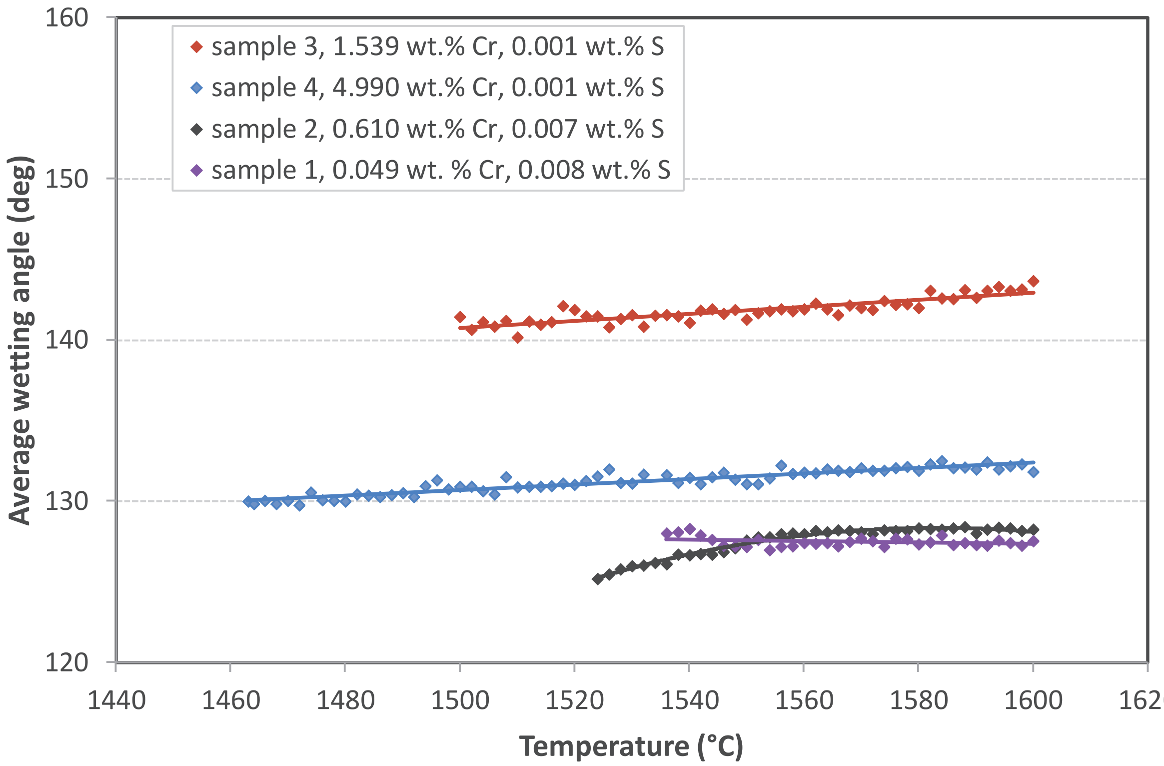
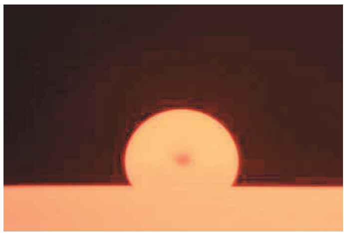


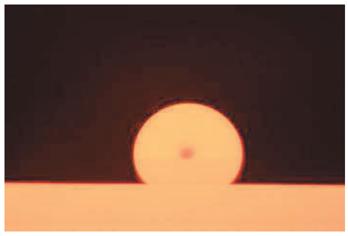
Figure 4 Temperature dependencies of average wetting angles of investigated steels on alumina substrate

The temperature dependencies of the average wetting angle of the steel samples 1 - 4 in the temperature interval from their melting point to the temperature of 1600 °C are shown in **Figure 4**. The temperature dependence of the sample 5 was omitted. Given sample contains the highest amounts of sulphur, almost ten times higher than samples 3 and 4, which can greatly affect the size of the contact angle between the molten steel and alumina substrate. The average contact angle of sample 5 with a sulphur content of 0.011 wt. % was about 107 °. From **Figure 4** it can be seen that with increasing chromium content increases the wetting angle, with the exception of sample 3, that as the only contains a higher amount of aluminum (0.820 wt. %). The average wetting angles for sample 3 is higher than for sample 4, probably due to the higher aluminum content. The images of the sessile drop of investigated steels on alumina substrate and their contact angles at a temperature 1580 °C are shown in **Figure 5**.

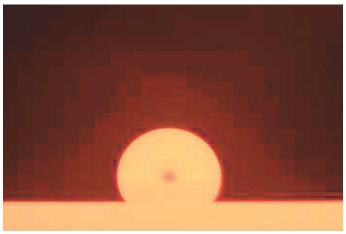
sample 1; 127 °



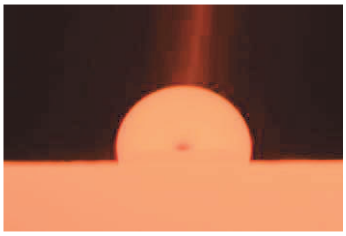
sample 2; 128 °



sample 3; 142 °



sample 4; 132 °



sample 5; 107 °

Figure 5 Images of the sessile drop of investigated steels on alumina substrate and their wetting angles at a temperature of 1580 °C

4. CONCLUSION

The results obtained by the experimental research can be summarized as follows:

- The surface tension of the investigated steel samples, with the exception of sample 2, decreases with increasing temperature. The temperature dependencies of surface tension exhibit a steeper decrease at higher chromium contents.
- The surface tension increases with increasing contents of carbon and chromium for all investigated steels. The positive effect of carbon and chromium on the surface tension of given steels is probably influenced by the presence of surface active elements - oxygen and sulphur. Carbon and chromium decreases the oxygen activity and consequently increases surface tension.
- The contact angle of liquid steel samples with alumina substrate increased with increasing chromium content. Wetting angle decreases markedly with the increasing content of sulphur.
- The wettability of alumina by investigated steels, with the exception of sample 1, increases slightly with increasing temperature.

Assessment of the impact of individual elements on the steel surface tension and wetting of steels with alumina substrate is very difficult for polycomponent systems. However, the aim of this experimental study was to determine the temperature dependencies of surface tension and wetting angles in real steel grades. Another analysis will be performed in the next step for confirmation of aforementioned assumptions.

ACKNOWLEDGEMENTS

This paper was created within the frame of the project No. LO1203 "Regional Materials Science and Technology Centre - Feasibility Program" funded by the Ministry of Education, Youth and Sports of the Czech Republic, the project GACR reg. number 17-18668S and the student project SGS (SP2017/59).

REFERENCES

[1] EGRY, I., RICCI, E., NOVAKOVIC, R., OZAWA, S. Surface tension of liquid metals and alloys - Recent development. *Advances in Colloid and Interface Science*, 2010, vol. 159, pp.198 - 212.

[2] KAWAI, Y., MORI, K., KISHIMOTO, M., ISHIKURA, K., SHIMODA, T. Surface tension of liquid Fe-C-Si alloys. *Tetsu - To - Hagane*, 1974, vol. 60, no. 1, pp. 29 - 37.

[3] MOROHOSHI, K., UCHIKOSHI, M., ISSHIKI, M., FUKUYAMA, H. Effects of carbon and oxygen on Fe-C-O melt surface tension. *ISIJ International*, 2013, vol. 53, no. 8, pp. 1315 - 1319.

[4] LEE, J., MORITA, K. Effect of carbon and sulphur on the surface tension of molten iron. *Steel research*, 2002, vol. 73, no. 9, pp. 367 - 372.

[5] JIMBO, I., CRAMB, A., W. Computer aided interfacial measurements. *ISIJ International,* 1992, vol. 32, no. 1, pp. 26 - 35.

[6] LI, Z., ZEZE, M., MUKAI, K. Surface tension and wettability of liquid Fe-16mass% Cr-S alloy with alumina. *Materials Transactions*, 2003, vol. 44, no. 10, pp. 2108 - 2113.

[7] MUKAI, K., LI, Z., ZEZE, M. Surface tension and wettability of liquid Fe-16mass% Cr-O alloy with alumina. *Materials Transactions*, 2002, vol. 43, no. 7, pp. 1724 - 1731.

[8] ROSYPALOVÁ, S., DUDEK, R., DOBROVSKÁ, J., DOBROVSKÝ, L., ŽALUDOVÁ, M. Interfacial tension at the interface molten oxide system/molten steel. *Materiali in Technologije/Materials in Technology*, 2014, vol. 48, no. 3, PP. 415 - 418.

[9] LEE, J., YAMAMOTO, K., MORITA, K. Surface tension of liquid Fe-Cr-O alloys at 1823 K. *Metallurgical and Materials Transactions B*, 2005, vol. 36B, pp. 241 - 246.