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Original article

Thermal properties of armour steel protac 600

Matic Lešnjak[1,2], *Borut Kosec[1,3], Blaž Karpe[1], Goran Janjić[4], Mirko Gojić[5], Jure Bernetič[6], Gorazd Kosec[2]

[1]*University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva cesta 12, 1000 Ljubljana, Slovenia*
[2] *SIJ ACRONI d.o.o., c. Borisa Kidriča 44, 4270 Jesenice, Slovenia*
[3] *University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva cesta 6, 1000 Ljubljana, Slovenia*
[4] *University of Banja Luka, Faculty of Mechanical Engineering, vl. S. Stepanovića 71, 78000 Banja Luka, BiH*
5 University of Zagreb, Faculty of Metallurgy, Aleja narodnih heroja 3, 44103 Sisak, Croatia
[6] *SAAT d.o.o., na Lipce 4, 4260 Bled, Slovenia*

ABSTRACT

Steels from the group PROTAC are distinguished by good mechanical properties and excellent armour properties even at small thicknesses. The mechanical properties of PROTAC 600 steel are known, while data on thermal properties (thermal conductivity, specific heat and temperature conductivity) are not available, so in the frame of our work we determined its thermal properties.
As the first part of the work, a study and evaluation of the operation of the device for determining the thermal properties of Hot Disk TPS 2200, today one of the more modern and high-quality instruments for determining thermal properties.
In the second part of the work, we performed measurements of thermal properties in accordance with the standard ISO 22007-2 at ambient temperature. The values of thermal properties of PROTAC 600 steel at ambient temperature (approximately 22 °C) are: thermal conductivity 28.69 W/mK, specific heat 3.94 MJ/m3K, and temperature conductivity 7.29 mm2/s. We found that steel PROTAC 600 has more than 10% higher heat conductivity in comparison with the steel of previous generation PROTAC 500.

Key words: *armour steel, properties, thermal properties, measurements;*

1. INTRODUCTION

Steel PROTAC 600 is the last generation of the steels from the family PROTAC. It belongs to the group of high strength low alloy (HSLA) steels. It is made in Slovenian steelwork ACRONI d.o.o. by the standard industrial procedures, and the relevant mechanical properties are achieved by quenching and tempering.
The selection of the appropriate armored material is crucial to ensure the adequate safety and mobility transport systems [1]. When selecting or developing the appropriate materials for the armor it is necessary to achieve the best possible compromise between the required mechanical properties of materials, minimizing the density and the final price of the product [2]. With the appropriate production technology, which includes synthesis, hot forming, heat treatment, etc. [3, 4] high strength low alloy steel of good functional properties at affordable prices can be produced.

By improving the strength and toughness of the steel the required thickness and the weight of the steel shell is reduced. Such steels are competitive to other materials for the armor [5].

2. BASIC MATERIAL PROPERTIES

Basic material properties of the armour steel PROTAC 600 are still well known. Chemical composition of the armour steel PROTAC 600 is represented in Table 1, mechanical properties are collected in Table 2, and microstructure is represented in Fig.1.

Tab.1 *Chemical composition of steel PROTAC 600*

Element	C	Si	Mn	P	S	Cr	Ni
Mass %	0.42	1.00	0.80	0.02	0.003	1.3	3.50

M	B
0.50	0.004

*Corresponding author's.e-mail: borut.kosec@omm.ntf.uni-lj.si

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Tab.2 *Mechanical properties of steel PROTAC 600*

Thickness	6.5 – 60 mm
Hardness	570 – 650 HB
Yeald strength $R_{P02,}$	1500 MPa
Tensile strength R_m	2100 MPa
Elongation A_5	9 %
Impact toughness (at testing temperature - 20 °C)	20 J

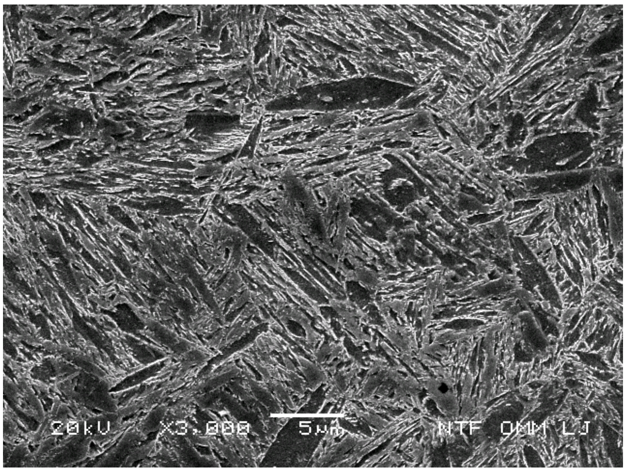


Fig. 1 *Martensitic microstructure of steel PROTAC 600 (SEM)*

3. THERMAL PROPERTIES

In our research, we used one of the most advanced instruments for determining the thermal properties, Hot Disk TPS 2200, a product of Hot Disk AB company, Gothenburg, Sweden (Figure 2) [6].

Fig. 2 *Instrument Hot Disk TPS 2200*

The instrument can be used for determining thermal properties of various materials including pure metals, alloys, minerals, ceramics, plastics, glasses, powders and viscous liquids with thermal conductivity in the range from 0.01 to 500 W/mK, thermal diffusivity from 0.01 to 300 mm2/s and heat capacity up to 5 MJ/m3K. Measurements can be perform in a temperature interval between -50 °C up to 750 °C.

Fig. 3 *Measuring sensor sandwiched between two halves of a sample during measurement*

Hot disk measuring method is a transient plane source technique (TPS). Based on the theory of TPS, instrument utilizes a sensor element in the shape of 10 μm thick double spiral (Figure 3), made by etching from pure nickel foil.

Spiral is mechanically strengthen and electrically insulated on both sides by thin polyimide foil (Kapton ®Du Pont) for measurements up to 300 °C or mica foil for measurements up to 750 °C (Figure 4).

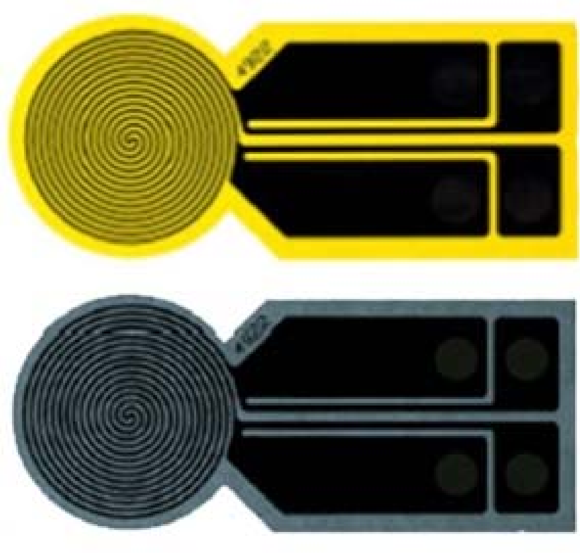


Fig. 4 *Sensor element (yellow-Kapton, gray-Mica)*

Sensor acts both as a precise heat source and resistance thermometer for recording the time dependent temperature increase. During measurement of solids, encapsulated Ni-sensor is sandwiched between two halves of the sample and constant precise pre-set heating power is released by the sensor, followed by 200 resistance recording in a pre-set measuring time, from which the relation between time and temperature change is established. Based on time dependent temperature increase of the sensor, thermal properties of the tested material are calculated.

3.1 *Experimental work*

Measurements and analysis of thermal properties of testing samples from the steel PROTAC 600 (Fig.5) were performed in accordance with ISO 22007-2 standard [7] in the Laboratory for Thermotechnical Measurements, Faculty of Natural Sciences and Engineering, University of Ljubljana.
In Fig.6 are presented results of thermal properties measurements.

Fig.5 *Testing samples (40 x 40 x 14 mm).*

In Table 3 are presented thermal properties (thermal conductivity, specific heat and temperature conductivity) of steel PROTAC 600 and steel PROTAC 500 (basic, main steel quality from the group PROTAC) [8, 9] at ambient temperature (approx. 22ºC).

Tab.3 *Thermal properties of steel PROTAC 600 and steel PROTAC 500 at ambient temperature*

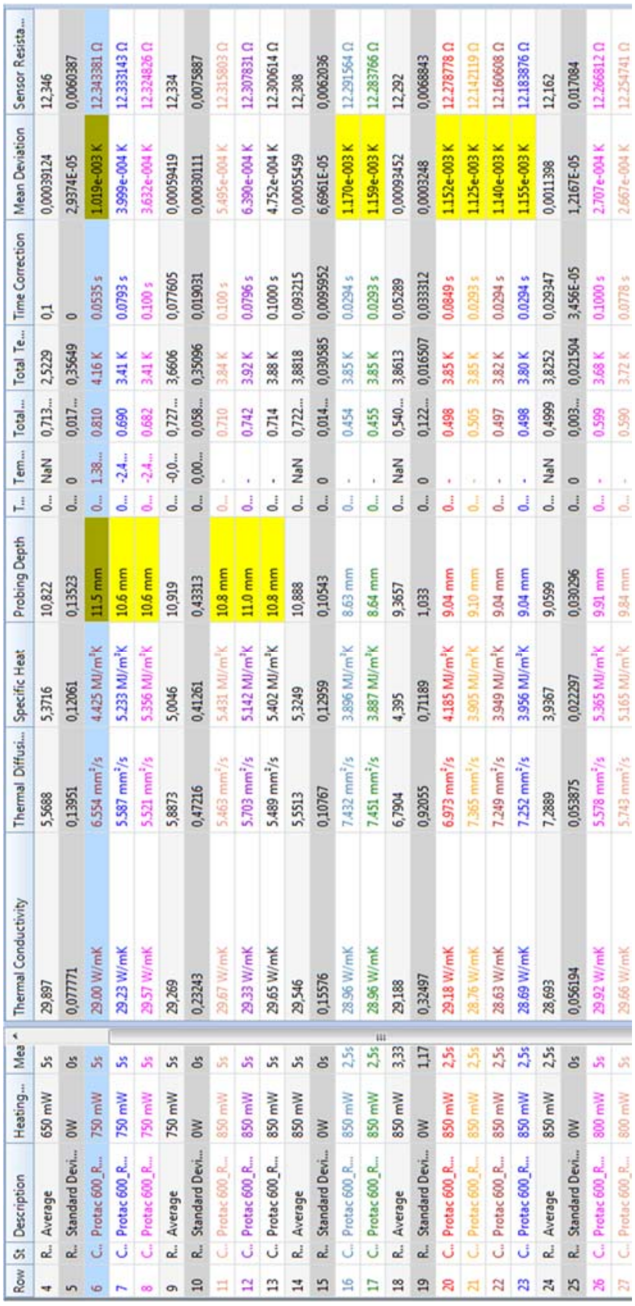
Steel	PROTAC 600	PROTAC 500
Thermal conductivity	28.69 W/mK	25.61 W/mK
Specific heat	3.94 MJ/m3K	3.76 MJ/m3K
Temperature conductivity	7.28 mm2/s	6.81 mm2/s

4. CONCLUSIONS

Steels from the group PROTAC are distinguished by good mechanical properties and excellent armour properties even at small thicknesses. The mechanical properties of PROTAC 600 steel are known, while data on thermal properties (thermal conductivity, specific heat and temperature conductivity) were not available, so in the frame of this work its thermal properties were determined. As the first part of the work, a study and evaluation of We performed measurements of thermal properties in accordance with the standard ISO 22007-2 at ambient temperature. The values of thermal properties of PROTAC 600 steel at ambient temperature (approximately 22 °C) are:

- thermal conductivity 28.69 W/mK,
- specific heat 3.94 MJ/m3K, and
- temperature conductivity 7.29 mm2/s.

We found that steel PROTAC 600 has more than 12% higher heat conductivity in comparison with the steel previous generation steel PROTAC 500.



Row	St	Description	Heating...	Mea	Thermal Conductivity	Thermal Diffusi...	Specific Heat	Probing Depth	T...	Tem...	Total...	Total Te...	Time Correction	Mean Deviation	Sensor Resista...
4	R...	Average	650 mW	5s	29,897	5,5688	5,3716	10,822	0...	NaN	0,713...	2,5229	0,1	0,00039124	12,346
5	R...	Standard Devi...	0W	0s	0,077771	0,13951	0,12061	0,13523	0...	0	0,017...	0,35649	0	2,9374E-05	0,0060387
6	C...	Protac 600_R...	750 mW	5s	29.00 W/mK	6.554 mm²/s	4.425 MJ/m³K	11.5 mm	0...	1.38...	0.810	4.16 K	0.0535 s	1.019e-003 K	12.343381 Ω
7	C...	Protac 600_R...	750 mW	5s	29.23 W/mK	5.587 mm²/s	5.233 MJ/m³K	10.6 mm	0...	-2.4...	0.690	3.41 K	0.0793 s	3.999e-004 K	12.333143 Ω
8	C...	Protac 600_R...	750 mW	5s	29.57 W/mK	5.521 mm²/s	5.356 MJ/m³K	10.6 mm	0...	-2.4...	0.682	3.41 K	0.100 s	3.632e-004 K	12.324826 Ω
9	R...	Average	750 mW	5s	29,269	5,8873	5,0046	10,919	0...	-0,0...	0,727...	3,6606	0,077605	0,00059419	12,334
10	R...	Standard Devi...	0W	0s	0,23243	0,47216	0,41261	0,43313	0...	0,00...	0,058...	0,35096	0,019031	0,00030111	0,0075887
11	C...	Protac 600_R...	850 mW	5s	29.67 W/mK	5.463 mm²/s	5.431 MJ/m³K	10.8 mm	0...	-	0.710	3.84 K	0.100 s	5.495e-004 K	12.315803 Ω
12	C...	Protac 600_R...	850 mW	5s	29.33 W/mK	5.703 mm²/s	5.142 MJ/m³K	11.0 mm	0...	-	0.742	3.92 K	0.0796 s	6.390e-004 K	12.307831 Ω
13	C...	Protac 600_R...	850 mW	5s	29.65 W/mK	5.489 mm²/s	5.402 MJ/m³K	10.8 mm	0...	-	0.714	3.88 K	0.1000 s	4.752e-004 K	12.300614 Ω
14	R...	Average	850 mW	5s	29,546	5,5513	5,3249	10,888	0...	NaN	0,722...	3,8818	0,093215	0,00055459	12,308
15	R...	Standard Devi...	0W	0s	0,15576	0,10767	0,12959	0,10543	0...	0	0,014...	0,030585	0,0095952	6,6961E-05	0,0062036
16	C...	Protac 600_R...	850 mW	2,5s	28.96 W/mK	7.432 mm²/s	3.896 MJ/m³K	8.63 mm	0...	-	0.454	3.85 K	0.0294 s	1.170e-003 K	12.291564 Ω
17	C...	Protac 600_R...	850 mW	2,5s	28.96 W/mK	7.451 mm²/s	3.887 MJ/m³K	8.64 mm	0...	-	0.455	3.85 K	0.0293 s	1.159e-003 K	12.283766 Ω
18	R...	Average	850 mW	3,33	29,188	6,7904	4,395	9,3657	0...	NaN	0,540...	3,8613	0,05289	0,00093452	12,292
19	R...	Standard Devi...	0W	1,17	0,32497	0,92055	0,71189	1,033	0...	0	0,122...	0,016507	0,033312	0,0003248	0,0068843
20	C...	Protac 600_R...	850 mW	2,5s	29.18 W/mK	6.973 mm²/s	4.185 MJ/m³K	9.04 mm	0...	-	0.498	3.85 K	0.0849 s	1.152e-003 K	12.278778 Ω
21	C...	Protac 600_R...	850 mW	2,5s	28.76 W/mK	7.365 mm²/s	3.905 MJ/m³K	9.10 mm	0...	-	0.505	3.85 K	0.0293 s	1.125e-003 K	12.142119 Ω
22	C...	Protac 600_R...	850 mW	2,5s	28.63 W/mK	7.249 mm²/s	3.949 MJ/m³K	9.04 mm	0...	-	0.497	3.82 K	0.0294 s	1.140e-003 K	12.160608 Ω
23	C...	Protac 600_R...	850 mW	2,5s	28.69 W/mK	7.252 mm²/s	3.956 MJ/m³K	9.04 mm	0...	-	0.498	3.80 K	0.0294 s	1.155e-003 K	12.183876 Ω
24	R...	Average	850 mW	2,5s	28,693	7,2889	3,9367	9,0599	0...	NaN	0,4999	3,8252	0,029347	0,0011398	12,162
25	R...	Standard Devi...	0W	0s	0,056194	0,053875	0,022297	0,030296	0...	0	0,003...	0,021504	3,456E-05	1,2167E-05	0,017084
26	C...	Protac 600_R...	800 mW	5s	29.92 W/mK	5.578 mm²/s	5.365 MJ/m³K	9.91 mm	0...	-	0.599	3.68 K	0.1000 s	2.707e-004 K	12.266812 Ω
27	C...	Protac 600_R...	800 mW	5s	29.66 W/mK	5.743 mm²/s	5.165 MJ/m³K	9.84 mm	0...	-	0.590	3.72 K	0.0778 s	2.667e-004 K	12.254741 Ω

Fig.6 *Results of measurements.*

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NOTE

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