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EFFECT OF HETEROGENEITY OF MATERIAL ON BALLISTIC RESISTANCE

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Abstract: *The aim of this paper is to investigate the influence of chemical heterogeneity of high-strength steels on the course of high-speed plastic deformation. The experiment was carried out on armor plate made of the Armox Advance armoured steel, which have undergone of high-speed plastic deformation at ballistic test by action of shots with caliber 7,62x39 mm. For this purpose, was made engineering shooting target in accordance with the standard.*

Keywords: *high-strength steel, ballistic resistance, hardness, chemical heterogeneity*

1. INTRODUCTION

The advance in armor protection technology development is closely connected with improving of mechanical characteristics of materials. We are constantly working on improving the chemical homogeneity and to minimize the amount of harmful elements in steel. New production technology of materials leads to a significant increase in their strength and hardness, and thus allows reducing the wall thickness of armored plate to a minimum. Reducing the wall thickness of armored plate leads to weight reduction of technique, material savings and thus the overall cost savings and in mobile technique to improve patency.

Important factor and indicator of quality of steels is their chemical homogeneity and exact compliance with the contents of alloy elements. To the uneven distribution of some elements often comes already during solidification of molten metal, or segregation in subsequent heat treatment.

One of the world leaders in production of high strength steels is a Swedish company *SSAB Oxelösund*, a member of *SSAB Svenskt Stal*. The company produces several types of high-strength steel plates, among which are the most important ARMOX plate type for special technique.

2. REALIYATION OF THE EXPERIMENT

An experiment was targeted on armor plate made of a material Armox Advance, which was part of ISO 1C container (Fig. 1) mounted with additional ballistic protection made up from material Armox Advance with thickness 7 mm of the walls of the container and 4 mm from the ceiling container. The floor is not armored. The container is produced by *Vývoj,* *a.s. Martin* and serves as special mobile communication workplace.

Manufacturers reported the chemical composition and mechanical properties of the material Armox Advance are listed in Table 1. According to manufacturer is this material the hardest material on the world. Its disadvantage is that when it is heated above 100 °C, leads to a thermally affected by a change in mechanical properties.

Table 1: Indicative chemical composition and mechanical properties of the material ARMOX ADVANCE

Indicative chemical composition [wt. %]			Mechanical properties		
C	max %	0,47	Hardness	[HRC]	58-63
Si	max %	0,7	KV -40°C	[J]	14
Mn	max %	1	Yield strength	[MPa]	min. 1600
P	max %	0,01			
S	max %	0,005	Tensile strength	[MPa]	2250
Cr	max %	1,5			
Ni	max %	3	Tensibility	A5	9
Mo	max %	0,7			
B	max %	0,005		A50	-

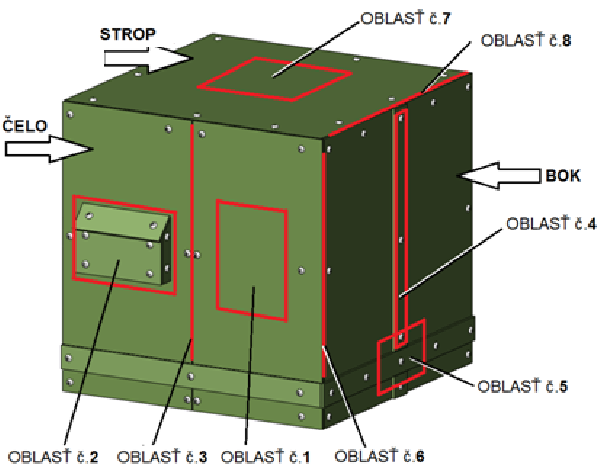

Fig. 1: 3D view of ISO 1C container showing the sample sites for ballistic testing

Ballistic tests were carried out on *VTSÚ Záhorie* and their purpose was to assess and recommend the provision of ballistic resistance at level STANAG 4569 Level 2 ISO 1C container. For tests were used 7.62 x39 mm (43 vz. PZ) ammunition. For each of taken targets 22 shots were fired, and their muzzle and impact velocities were measured. The terms of STANAG 4569 Level 2 meet all samplings, except for SS-3 samples taken from the front of container (Fig. 1, area 1).

The engineering target (SS-3) shown in Fig. 1 analyzes were performed, which aimed to determine the values of hardness and chemical composition of the material. As a first hardness test was performed and after the chemical analysis of material.

Fig. 2: Sample SS-3

According to the report of the ballistic analysis was on target in terms of requirements of STANAG 4569 Level 2 fired 22 shots, Impact speed of shot no. 14 was 714.7 m / s and penetration occurred. The same was also with shot no. 18, which is 51 mm away from no. 14. In the area of shots no. 14 and 18 (Fig. 3) was taken a sample with size 270x160 mm with angle grinder. The cut was made at a sufficient distance from both of breakdowns, as not to thermal influence the structure in their area. At the same time the sample was therefore also cooled.

Fig. 3: The locations of the sample target shots

The sample was also hand-sanded with sandpaper on the back and hardness measurement was performed.

2.1 Hardness test. The hardness measurement was performed on the measuring device INSTRON WOLPERT TESTOR 930 on different areas of sample. A total of 18 measurements were carried out. The fields of measurements are shown on Fig. 4. and measurements results are shown in Table 2. Before measuring of hardness of the sample was carried out verification of correct calibration of measuring equipment on a standard, which upheld the device.

<u>Characteristics of the test</u>:

- Vickers hardness test, STN EN ISO 6507-1
- Test equipment: Multipurpose hardness tester Instron Wolpert Testor 930
- Testing Methodology: HV5, loading F = 49,03 N, t = 8 s, indentor - tetrahedral diamond pyramid 136°

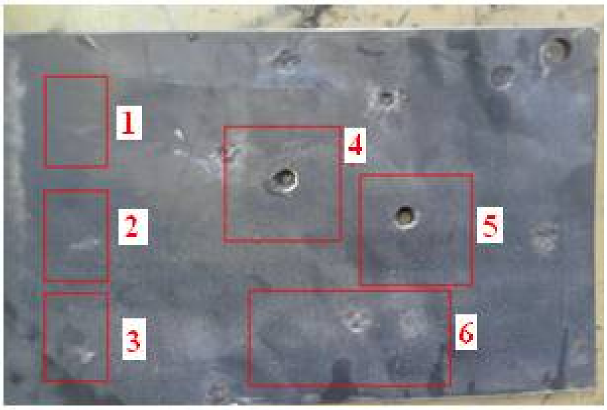

Fig. 4: Areas of hardness measurements on a sample

2.2 Analysis of chemical composition. Analysis of chemical composition was performed on the device **SPECTROLAB, Jr CCD.** Before chemical analysis of sample was carried out verification of correct calibration of measuring equipment on a standard, which upheld the device.

<u>Characteristics of the test</u>:

- Spectral analysis of chemical composition by atomic emission spectrometry (AES), STN EN 10351: Chemical analysis of ferrous materials. Optical emission spectrometric analysis with inductively coupled plasma carbon, low and medium alloy steels. ISO 14700:2000: Surface chemical analysis - Glow discharge optical emission spectrometry (GD-OES).

A total of 3 measurements were made where sites are marked in Fig. 5. First measurement point M1 is located 86 mm from nearest penetration.. The second measurement M2 was performed directly on the projection caused by plastic deformation of bullet that don’t break the target and is located 65 mm from from nearest penetration. Measuring point M3 is only 22 mm from nearest penetration. The results of measuring are shown in Table 3. All final values are given in wt. %.

Fig. 5: Location of the chemical analysis (M1, M2, M3)

2.3 Evaluation of analyzed material

Table 2: Results of HV5 hardness measurements

Area	Hardness HV5	The average value
	477	
	442	
1	457	458,7
	484	
	460	
2	436	460
	435	
3	450	442,5
	407	
4	414	410,5
	393	
	397	
	402	
5	408	400
6	453	457,3
	457	
	503	
	416	

Table 3: Observed chemical composition at the M1, M2 and M3 [wt. %]

Chemical composition	The number of measurement		
	M1	M2	M3
C %	0,2094	0,3896	0,2046
Si %	0,1640	0,1590	0,1320
Mn %	0,5910	0,5540	0,5730
P %	0,0075	0,0045	0,0091
S %	0,0042	0,0075	0,0080
Cr %	0,4900	0,4700	0,4900
Ni%	2,3500	2,3700	1,9500
Mo %	0,3664	0,3459	0,3613
B %	0,0003	0,0040	0,0015

3. CONCLUSIONS

From the results of spectral analysis shown in Table 3 we can see significant fluctuations of value of carbon and heterogeneity of the chemical composition of steel. Compared to the manufacturer dictated values of carbon (max. 0.47%) are below our measured values up to more than 50% (instead of measuring M3 and M1, the amount of carbon 0.2046% and 0.2094%). On the measuring point M2, the value of C was permissible and in this case there were no penetration of bullet.

Chemical heterogeneity of material caused a considerable scatter of hardness values, while the largest decrease in hardness was observed especially in the area of penetrations. In neither case was our measured value of hardness in accordance with the manufacturer entered values. It follows that the effect of chemical heterogeneity on the ballistic resistance of the material is very strong, and materials, involving a failure to comply with the percentage of alloy elements is necessary excluded from the manufacturing process and to eliminate from use for ballistic protection.

REFERENCES

1. Híreš, O., Barényi, I., Ličková, M., Bednárik, D.,. *Expertíza material ARMOX ADVANCE po balistických skúškach*. Výskumná správa, Trenčín, 2012
2. HÍREŠ, O.: *Fyzikálna metalurgia ocelí a ich tepelné spracovanie.* Trenčín: GC TECH, 2006. ISBN 80-8075-099-8
3. STANAG 4569 – Protection levels for occupants of logistic and light armoured vehicles, 2004
4. SSAB Oxelösund AB, Sweden: *General Product Information WELDOX, HARDOX and ARMOX.. Source.* [online]. Available: <http://www.oxycoupage.com/FichiersPDF/English/brochure_information_en.pdf>