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The Suitability of Using C30E Steel Materials for Damping the Effects of Improvised Explosive Devices[*]

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Abstract. There are nowadays different kinds of homogenous steel armours (e.g. different kinds of steel sheets Armox, Russian armours including 2P, 43 PSM etc.) or aramide fibres which can be used alone or in composites. This paper follows the relationship between the strength parameters and microstructure in the steel armours used for personal protection and military vehicles. The results described in the paper, pick up the threads of previous work performed at the Mechanical Engineering Department in Armed Forces Academy of gen. M.R. Stefanik in Liptovsky Mikulas.

Keywords: materials engineering, homogenous armours, metallographic observation, material hardness, microhardness, tenacity, toughness

1. INTRODUCTION

During explosions of terrorist improvised explosive devices there is a great deal of destruction which takes place within the surrounding materials. Destruction is the result of the integration of high temperature from ignition of explosives (2500÷5000°C), high gas detonation pressure (1000÷20 000 MPa) and explosion energy (6000 kJ/kg).

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Researching behaviour of protective materials for the above conditions can be found useful further in increasing the resistance of thin steel armour plates against the effect of improvised explosive devices. This applies both to monitoring changes in the structure of thin steel armour plates after the effect of operation of improvised explosive devices, but also vibrations in the material during such action, which can be reliably detected using vibrodiagnostic methods. By examining the relationship of strength parameters and microstructure of steel materials used for personal protection as well as for vehicles (AFV – Armoured Fighting Vehicle) and for protected objects (safes, sheltered structures) our results show the behaviour of steel materials in terms of classical tests for the implementation of the notch toughness at temperatures where the person normally moves.

2. CHEMICAL COMPOSITION COMPARISON OF SELECTED MATERIALS

Chemical composition of steel alloys has a significant role in determining properties of a particular alloy. The ability to resist the action of shooting projectiles or pressure waves from explosions is given by the characteristic properties of the material including its tensile strength, yield strength, elongation and contraction of the material. In addition to these we are interested in the material toughness as the ability to stay intact in bending and upon impact, without formation of cracks. The opposite is fragile.

For our investigation we have chosen the Swedish material ARMOX 500T and a second material: EN C30E steel which is produced in Slovakia. The materials are listed in Table 1.

Table 1. Chemical composition of studied steel materials

	Chemical composition %								
	C	Mn	Si	Cr	Ni	Mo	B	P	S
Steel 12 031 (EN C30E)	0.34	0.80	0.40	0.40	0.40	0.10	-	0.035	0.035
Armox 500 T	0.32	0.804	0.2773	0.417	0.893	0.3569	0.0003	0.0068	0.0045
Difference	-0.02	+0.004	-0.1227	+0.017	+0.493	+0.2569	+0.0003	-0.0282	-0.0305

The chemical composition of steel alloys significantly affects the impact strength outside the crystal. Materials with an ideal crystal lattice (without dislocations) are fragile. Tough materials have less tensile strength, but with a great ability of absorbing shocks.

Table 1 shows the chemical composition of the two steel materials.

Both materials are examined in terms of its constituents with the only difference being in the boron, which is not available for the C30E steel. In terms of toughness of the material we are most interested in manganese, silicon and nickel. Alloys in ferrite-pearlite steels, are used to increase the yield stress and strength of the ferrite. These features affect the manganese, silicon, chromium and nickel.

Manganese is used for the substitution of hardening of ferrite. It is less common to use silicon and nickel for this purpose. Manganese is a readily available and relatively inexpensive element, although the increase in yield stress is not so strong, it has the advantage that the current transient temperature shifts to lower temperatures. Silicon increases the strength and yield stress, but in the contents of 0.7% impact strength decreases sharply. Opposite is in the ferritic – chrome steels, where the contents of silicon and manganese is low, because they increase transient temperature. Their negative impact is already reflected in the presence of 1% manganese and 0.5% silicon.

Nickel dissolved in ferrite increases the value of notch toughness and the temperature gradient significantly shifts towards lower temperatures. Nickel is a relatively expensive element, so it is used only for steel refining in which we get the maximum of the mechanical properties. This is true for ferrite-pearlite steels. Although nickel increases the strength of ferrite, it does not reduce its impact strength. During the rapid cooling from the area of stabile austenite ferrite alloyed by Cr, Mn, and Ni transfer without diffusion martensitic transformation.

Molybdenum improves the process of hardening and increases the strength of the material. Resistance against softening at higher temperatures and therefore higher content causes problems with forging.

Boron atoms are deposited preferentially at the grain boundaries, where they hinder the diffusion of carbon atoms and inhibit secretion of ferrite. Boron extends the start of austenitic transformation and thus also improves hardness properties.

It shows great efficiency for absorption of neutrons and is used for alloy steels intended for controllers and devices to screen nuclear energy. Boron improves the strength characteristics of austenitic steels resistant to high temperatures. This element in the structural steels improves hardness properties and the amount required to do this is of two orders of magnitude smaller (0.001%) than required amount of carbon to achieve similar effect. It causes an increased core strength in cemented steels. Very small amounts of boron in the material are hardly detectable and can affect the hardening properties, which causes problems for machining. It also reduces weld ability.

Sulphur is contained in steel as an impurity during the production. On the one hand it makes heat treatment difficult; on the other hand, it improves the workability of the material.

Phosphorus is also an impurity incured during production similar to sulphur and therefore is included in steel. It increases tensile strength and resistance to atmospheric corrosion. In conclusion to this chapter we can conclude:

Effect of the chemical composition on impact strength is as follows: chromium reduces very slightly the impact strength (if not exceeded 2%), nickel increases the impact strength, molybdenum, tungsten and manganese decrease the impact strength when presented in content higher than 1%, boron improves the hardness, but worsens the steel’s weldability.

3. SELECTED MECHANICAL PROPERTIES OF TESTED MATERIALS

To achieve our goal, we selected the basic mechanical properties of selected steels’ hardness and notch toughness.

Notch toughness is the material ability to withstand sudden, shock loads. This feature is similar to resistance to penetration and it is dependent on temperature. Notch toughness is measured using specially prepared testing sample with a notch. It is indicated by the KCU, or KCV (according to U or V shape) and it is given in J/cm^2. Also indicating the temperature at which it was detected.

Impact strength is measured using a special device – Charpy hammer. It is a pendulum hammer with an established prescribed edge. The sample is positioned in order to notch up lying in the plane of swing motion of the hammer at the point with the most kinetic energy. The hammer is actuated by the gravitational force. The edge of the hammer strikes the sample from the opposite side as the notch up.

Test samples are small blocks of prescribed size with carved notches. Energy effect direction of the hammer and shape and dimensions of the specimen with the “V” notch for testing performance are depicted in Figure 1.

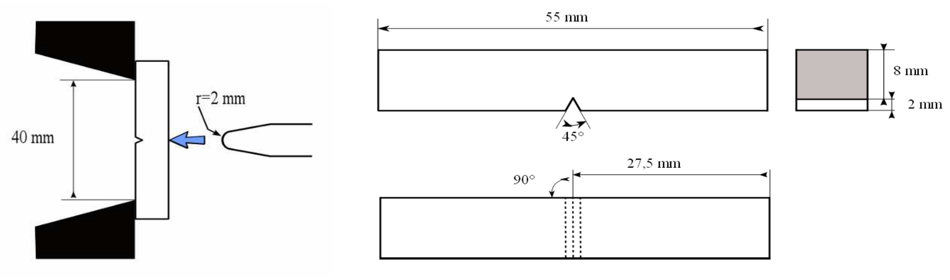


Fig. 1. Sketch of the sample location in the test equipment

To the right, indicated tip of hammer, test samples and size and shape of the sample.

3.1. Assessment of the fracture

In addition to the size of the notch, toughness is also an important result of the assessment of the fracture surface. According to the ratio of glossy and matte surfaces it can be assessed if the material is ductile or brittle.

Elongation is the material's ability to be plastically stretched. Plastic means that there are no cracks and the material will remain stretched. This is also the figure (in %) measuring the degree of irreversible extension of the profile.

Any material which has discolorations it its crystal lattice, may be elongated. The ideal lattice without dislocations allows no elongation. Due to the action of external forces, the dislocations move in the direction of The Burgers vector. Finally they reach the grains boundaries. Visually this would manifest for example as a matte surface.

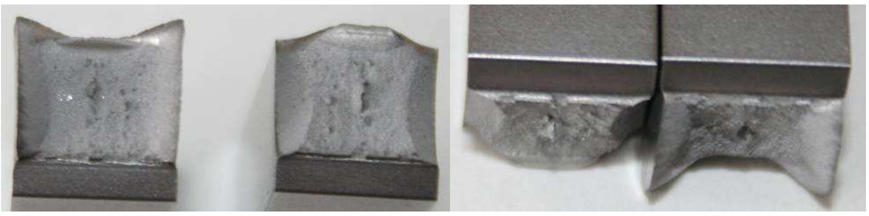


Fig. 2. Fracture surface of ductile material

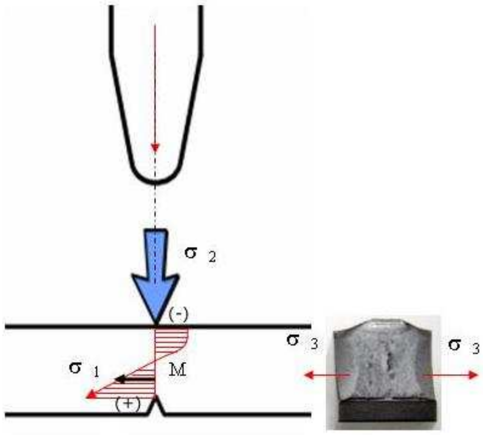


Fig. 3. Scheme of deformation caused by stress

Figure 2 shows the fracture surface of ductile material. Fracture surface is characterized by the homogeneity of the surface. The entire area is only an area of ductile (tenacity) fracture. The figure also shows deformation which causes stress which arises as a result of the bend in the notch.

3.2. Mechanical properties of tested materials

The measured values of selected mechanical properties are shown in Table 2. The values of ductility, tensile strength and yield stress are given by the manufacturer of the material.

From the measured mechanical properties at an ambient temperature of 20°C we can see, that the Armox 500T material has a high hardness and notch toughness. The sample has relatively high carbon content.

The C30E steel has a hardness of 265 HB after hardening. There is a significant change in the size of the notch toughness. The specimen had in its supplied state the hardness of 202 HB, with the impact strength being only 13.75 J/cm^2 and a typical fracture surface was brittle (crystalline fracture).

Table 2. The measured mechanical properties at 20°C

	Steel 12 031 (C30E)				Armox 500T
Values	Supplied state	Hardened	Tempered	Standards annealing	Supplied state
Macrohardness [HB]	202	265	139	142	484
Microhardness [HV$_M$]		240÷380	127	143	270÷650
Notch toughness [J·cm^{-2}]	13.75	102			92
Ductility A5 [%]	7.5	12.75			12
Breaking strength [MPa]	595	943	480	490	1 500
Yield strength [MPa]	594	869			1 250
Carbon equivalent	0.62				0.707

Fig. 4. Fracture surface of tested material C30E in the supplied state

A comparison of the chemical composition shows that the material properties of Armox 500T are affected by the amount of components (nickel, molybdenum and boron).

4. MICROSTRUCTURE COMPARISON OF SELECTED MATERIALS

On the fracture and etching surface of steel we can see the structure, which consist of a large number of grains. The size of these grains has effect on the mechanical properties of steel, but also on its behaviour during heat treatment. Heat treatment has a significant effect on the grain size.

In our case, we focused on the evaluation of the actual grain in the C30E steel in a supplied state and after heat treatment.

4.1. Comparison of grain sizes studied materials

We can claim that the Armox 500T material is supplied in the state, which is very beneficial for use in protecting against explosions or against bullets from small arms.

The measurements were made using a QuickPHOTO CAMERA 2.2. Reported values are given in Table 3.

Table 3. Characteristics of grains material Armox 500T

The average of grain area	μm^2	90.1
The measured area	μm^2	80115
The number of grains per 1 mm^2		11198
Grain size		10

The Armox 500T material can be classified in accordance with STN 42 0463 as a material with a grain size of 10. The grain characteristic of the C30E material before heat treatment is shown in Table 4. Table 5 shows the grain characteristic of the C30E material after hardening.

We can note that the C30E material comes to use in the state, in which it is very beneficial for protecting against explosions or against bullets from small arms. But after heat treatment it greatly changes its impact strength and to some extent increases its toughness.

Table 4. Characteristics of the grains C30E material in a supplied state

The average of grain area	μm^2	595.36
The measured area	μm^2	80115
The number of grains per 1 mm^2		840
Grain size		7

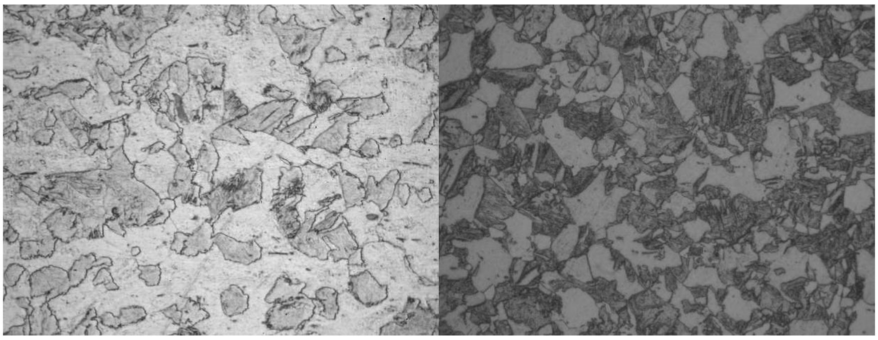
Table 5. Characteristics of the grains material C30E after hardening

The average of grain area	μm^2	755.1
The measured area	μm^2	80115
The number of grains per 1 mm^2		1273
Grain size		7

The values given in the table shows that the hardened C30E material was fine-grained. Also there is an increase in its number within the measured area. Despite its grain size according to the standards, it stays in group number 7.

4.2. Comparison of microstructures of tested materials

The Figures 5 and 6 are illustrated for comparison of shapes of grain and their layout. Figures were taken with an Olympus SP-350 camera from an Olympus GX-51 microscope. Magnification set was 1000 x, Nital 2%.etched.



a) b)

Fig. 5. The microstructure of the C30E material: a) in supplied state, b) after hardening

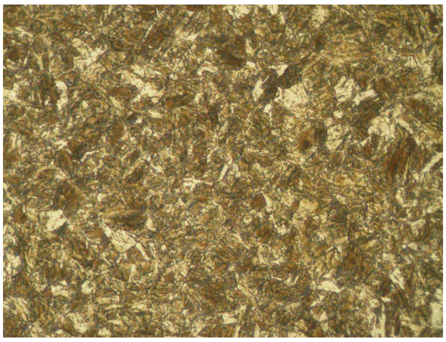


Fig. 6. The microstructure of the Armox 500T material in a supplied state

Comparing the shape of the microstructure we can evaluate the Armox 500T material. It has a structure in which the components of the heat treatment are predominant. These include especially bainite, martensite and carbides. After the hardening, structure of the C30E is dominated by ferrite.

5. CONCLUSION

After testing and comparison of mechanical properties of the Armox 500T and C30E materials we reach the following conclusions:

- the C30E material after hardening shows significant changes in its impact strength value measured at T = 20°C,
- the investigated C30E material without heat treatment shows a negligible impact strength value of 13.75 J/cm^2,
- the fracture surface shows that the C30E material is brittle.
- the C30E material after hardening did not reach such values of micro- and macrohardness as the Armox 500T material, although the impact strength value was similar.

After tempering or annealing of the C30E material, our testing device for impact strength measurement was unable to break the specimens.

This fact leads us to believe that further modification of this material could result in its improvement. Further efforts will focus on carburizing and its effect on surface hardness of the C30E material and the measurement of notch toughness after heat treatment at temperatures of this material’s normal use (–30°C÷+20°C).

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