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TEST FOR PENETRABILITY OF 10GHMBA STEEL USED FOR THE BALLISTIC SAFETY SHIELDS

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Abstract

There are elaborated some dependences which make it possible to compute some materials resistant to hits with the energy greater than in so far tests of the bullets of 7,62 mm caliber. The tests of being resistant to hit have been carried out with the 10GHMBA steel which has been overshot by the bullets of 12.7 mm. In order to do that the single cover plates with changeable thickness have been placed in the ballistic pendulum. On the basis of the obtained measurements like speed before and behind the specimen, the pendulum deflection angle, the force passed to the dynamometer sleeve, it is possible to define the maximum thickness of the penetrated material. The comparison with the bullets proof of various materials like steel with composites, ceramics or the mathematical models verification by an experiment can be done with direct comparison of some chosen measured parameters. For example the bullet speed behind the specimen has to be related to its thickness similarly to some other parameters which are possible to be measured. All the quantities like the bullet speed behind the specimen are the functions of the specimen thickness for the defined type of bullet. The penetration process of the material is a kind of transformation of the energy carried by the bullet into the energy of the specimen deformation, the emitted warm or into the pendulum work. In order to compare the bullet proof with various materials or the mathematical models with experiment there is proposed getting in some non-dimensional factors which define the change of the kinetic energy or the system impulse

Keywords: *ballistics, ballistic properties of steel, penetration of the shield, ballistic thickness of steel, penetration, perforation of the shield.*

1. Introduction

It is required towards some ballistic materials that during penetration a bullet must load dynamically a ballistic shield in proportion to exceed its resistance and then it must penetrate it and finally puncture it. To this end the bullet has to have a large speed, density, high resistance (to preserve a proper shape), a proper length toward penetration way and also a large density of the kinetic energy in a cross section of perforation (in a cross-sectional area of the bullet on a shield during perforation it) [8]. Materials designed for vessel ballistic shields should demonstrate the highest module of the volumetric-strain, the highest module of the lateral elasticity, the highest resistance, density and gauge. The punch resistance of the armored shield can be increased by means of using many armor layers of different materials. The mechanism of punching process reveals various variations. They depend on material characteristics of the bullet and the shield what make the correct description of the final ballistics process much difficult [4-8].

Compare the bullet-proof of different materials i.e. armored steel with composites, ceramics, plate constructions or verification of the mathematical models by experiments have to be done through compare the selected measured parameters in direct way. All the quantities like maximum gauge of the punched shield made of a proper material or the bullet speed behind the specimen should be different functions of the specimen gauge for different types of bullets. Punching process of given material is a conversion of the bullet energy into the energy of the specimen strain, into heat emission, pendulum work etc.

Making possible to compare the bullet-proof of different materials or different mathematical models with experiments by means of introducing the dimensionless coefficients which enable to define the change of kinetic energy or the momentum of the system elements is the fundamental goal of this elaboration

2. Ballistic tests of 10GHMBA steel

In different countries there are strictly defined requirements for ballistic shields and because of escalation of the terroristic attacks they are increased to caliber 12.7 mm. The ballistic resistance of given material depends not only on material properties but on the geometry and material parameters of the bullet as well. Therefore defining the material parameters for caliber 12.7 mm ought to be treated as a new issue with using the experiences obtained during ballistic tests for caliber 7.62 mm. The bullet-proof tests were carried out on the unified ballistic stand adapted to define the parameters during punching the shields by bullets of 12.7 mm caliber [8, 9].

The steel 10GHMBA – E620T was put to the tests. This steel is elaborated and patented material in Navy Academy as a high hardness steels destined for the ballistic shields [4, 8].The chemical constitution of it is presented in Tab. 1.

Tab. 1. The chemical constitution of the steel 10GHMMBA

Sheet gauge [mm]	The chemical constitution %													
12	C	Mn	Si	P_{max}	S_{max}	Cr	Ni	Cu	Mo	V	Nb	Ti	Al	N_2	B
	max 0.10	0.60 1.00	0.15 0.35	0.015	0.010	1.00 1.40	0.40 0.60	0.25 0.45	0.40 0.60	- -	0.015 0.035	0.010 0.030	0.02 0.06	max 0.009	0.025 0.045

Basic properties of 10GHMBA - E620T steel are defined on the basis of static blocking out test carried out on the electro-hydrodynamic resistance machine of MTS 810.12 type [8].

On the basis of the results there are determined the following quantities:

– Young's modulus E = 209.073 GPa,
– limit of proportionality Hook's R_H = 518.5 MPa,
– creep limit $R_{0.2}$ = 695 MPa,
– tensile strength R_m = 758.5 MPa.

The specimens for punching steel tests were made of sheet with dimensions: 1000 x 500 mm and gauge of 35 mm, 36 mm. Disks of 120 mm diameter were made by means of water jet technology in Treatment Center OMAX 55100 [8]. The cut disks with 120 mm diameter were under machining. The specimens 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34 and 36 mm of gauge were prepared for fire. For each gauge there were prepared 3–5 specimens with different numbers on each of them. For punching tests of these specimens there were used an armor-piercing bullet B-32 of 12.7 mm caliber.

General data of the bullet B-32 are as follows:
- tube caliber – 12.7 mm,
- bullet diameter – 12.95 mm,
- bullet length – 64.5 mm,
- bullet mass - 49 g.

3. The results of bullet-proof measurements of 10GHMBA steel

Tests which had been carried out in military training ground let us registrate the bullet speed before the specimen, the bullet speed behind the specimen, the angle of pendulum deflection and also the force applied to dynamometrical sleeve. There is also made up a photographic documentation for each specimen. The specimens have been overshot by threefold for each gauge i.e. 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36 mm, every 2 mm. In case when there was no reading of parameters on the recording system, the test for a given specimen gauge was repeated. By each shoot the bullet speed before the specimen was checked up-to-date and it amounted to 815-833 m/s. The average velocity was 824 m/s [8].

A detailed analysis which was made on the basis of superfast cameras proved that the bullet muzzle after shooting over the shield is not always horizontal. The consecutive frames presenting the stages of the bullet course after shooting over the specimen-the shield constitute a proof of it –(Fig. 1). The specimens after shooting over were photographed facing, in the back and on the side [8].

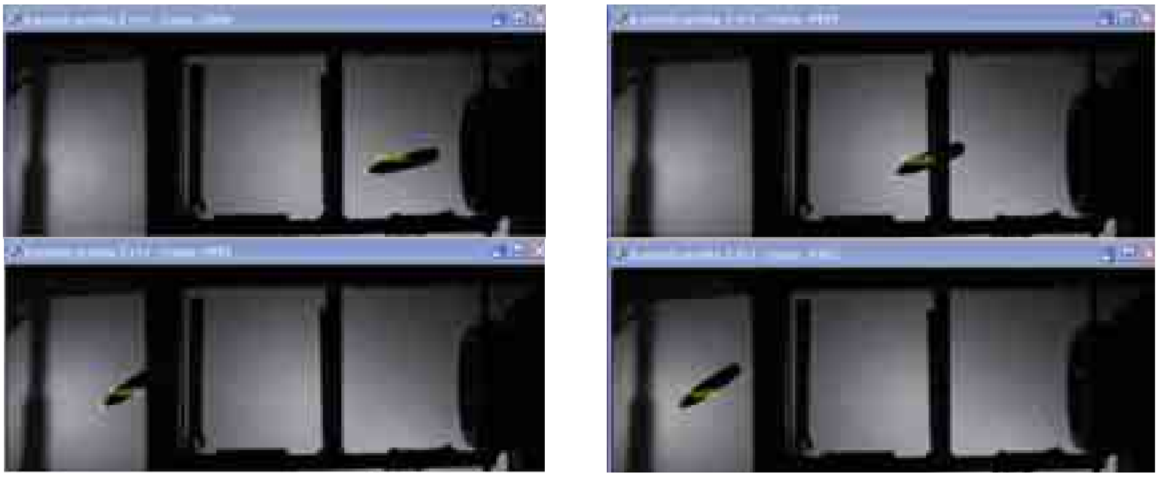

Fig. 1. The curvilinear motion of the bullet after shooting over the shield-specimen

The test proved that the gauge of shield made of the 10GHMBA-E620 steel –armor-piercing bullet-proof (B-32, caliber 12.7 mm) is 32 mm. The superfast cameras let, on the basis of the individual frames, to observe the motion of the bullet and the shock wave after leaving the bullet shooting over the shield (Fig. 2).

Fig. 2. The motion of the bullet and shock wave after the specimen-shield piercing by the steel bullet of 12.7 mm caliber

Figure 3 presents an example specimen after shooting over which was photographed facing, in the back and on the. On the basis of the read-outs from the oscillograph records there is determined the bullet speed before and behind the specimen [8].

Fig. 3. The view of specimen after shooting over, facing, in the back, the on the side

Figure 4 and 5 illustrate the average results of testing the specimens made of 10GHMBA steel piercing.

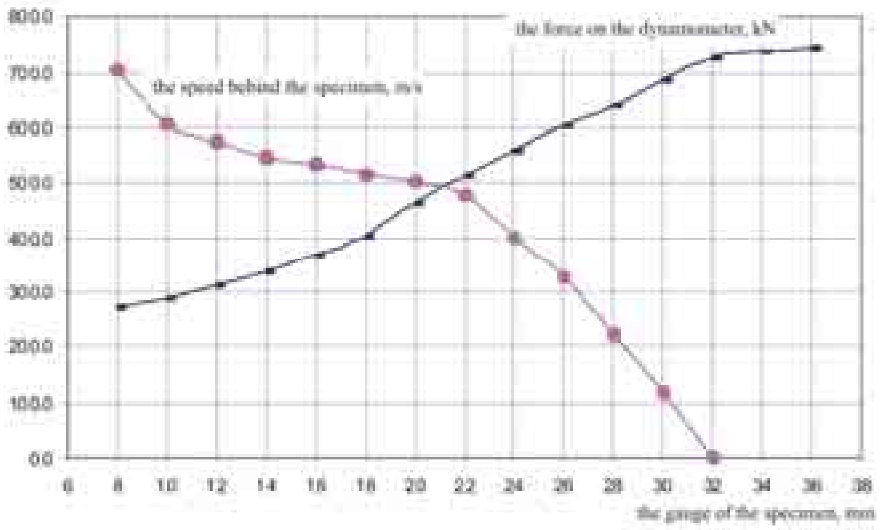

Fig. 4. The bullet speed behind the specimen and the force on the dynamometer as a function of the specimen gauge

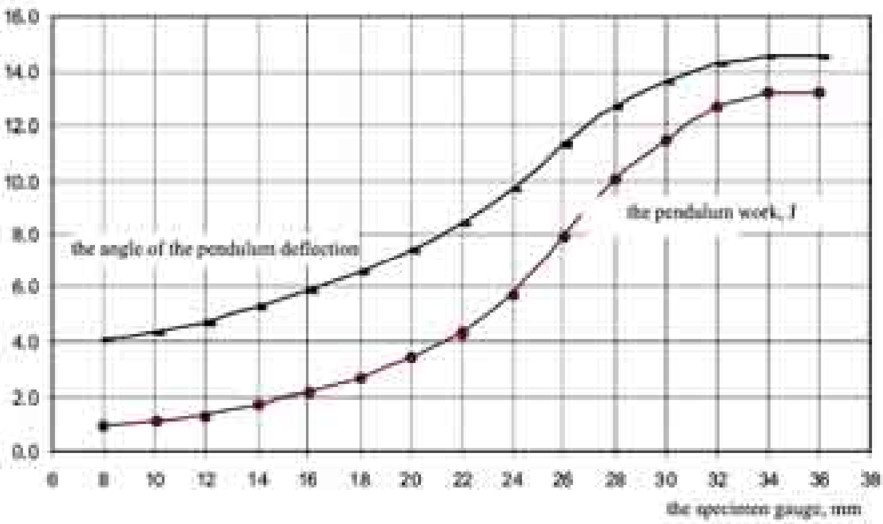

Fig. 5. The angle of the pendulum deflection and the pendulum work as a function of the specimen gauge

4. The bullet-proof analysis of the 10GHMBA steel

There have been also investigated the stress state in the shield and the failure during perforation in the microscope. Fig. 6. illustrates the cross-section of a 10 mm thick shield at the ballistic limit [2], there are also obtained some interesting observations. The first point, where the low lines are very distorted, is according to compression. The point rapidly ends when the plug is set in motion by the moving projectile and the deformation mechanism changes into a localized shear zone throughout the shield gauge. It is seen in Fig. 6. that the width of the intense shear zone is practically constant. When the plug has moved approximately half a plate gauge, the fracture occurs. This final point combines the shear and the tensile stresses. It is also noticed that the fracture begins at the projectile-plug interface and spreads out towards the back surface. Moreover, let us notice that when the plug is completely free on one side, cracking has just started on the other side [1].

Such unsymmetrical fracture mode is responsible for the observed plug rotation after the total separation. The fracture surfaces and the different fracture morphology areas have been observed in detail in the scanning electron microscope. Fig. 6. shows two typical pictures from the tests.

From the front face to the back side of the shield there is easily seen a sharp edge of the indentation with no front bulge, followed by a shear area smoothed by the passing projectile [1].

Towards the back side, a hollow of the shear area appears. In the concentrated shear zone, voids are initiated. Due to the continuous straining, the voids grow and elongate. The voids then unite due to the fracture of the thin walls separating the voids, giving the hollows, and then the crack is grows. Such process denotes ductile fracture [3]. What is more, the area in front of the crack tip has been studied. There are found a few elliptical cavities along the localized shear area, showing how the voids nucleate, grow and unite in front of the crack to form the ductile fracture [1].

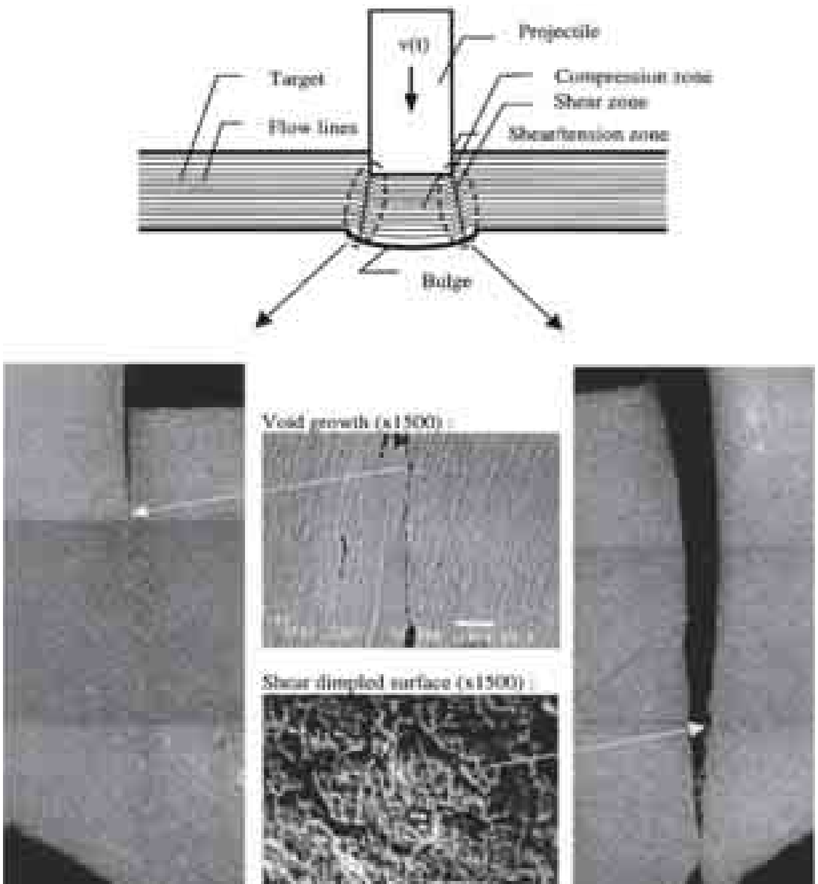

Fig. 6. Metallurgical pictures of the localized shear area (x 32). Notice that the pictures showing the shear areas are constructed on the basis of on several photos [1]

To compare the bullet-proof of various materials we need to compare those parameters which have been directly measured. In order to do that there are introduced some dimensionless coefficients which define the percentage change of the kinetic energy or the momentum of the system components. The measured quantities are as follows: the speed before and behind the specimen, the angle of the pendulum deflection on the basis of which the work of pendulum in order to overcome the force of gravity is calculated, and also the force passed to dynamometric sleeve during piercing the specimen by the bullet. On the basis of the above mentioned parameters a definition of some comparative coefficients is proposed (i-iii):

i. A_1 – a pendulum work

The bullet during piercing the specimen causes the deflection of the ballistic pendulum. The maximum angle φ_p of the pendulum deflection is recorded and on the basis of its deflection there is computed a real work of pendulum W_p to overcome the gravity force by displacing its gravity center on a given height. That work follows from the part of the kinetic energy carried by the bullet. That work is equated to the theoretical work W_W which a pendulum would do in case when the whole kinetic energy delivered by the bullet was used to do it. Then the pendulum would deflect by the angle φ_W.

When the bullet will not pierce the specimen those quantities are as follows:

$$W_w = \frac{1}{2}\cdot\frac{m^2\cdot l^2}{I_z + m\cdot l^2}\cdot\upsilon_p^2 \quad \cos\varphi_W = 1 - \frac{m^2\cdot l^2}{2\left(I_z + m\cdot l^2\right)}\cdot\frac{\upsilon_p^2}{(M+m)\cdot g\cdot s}, \tag{1}$$

while in the opposite case (piercing the specimen):

$$W_w = \frac{1}{2}\cdot\frac{m^2\cdot l^2}{I_z}\cdot\upsilon_p^2, \quad \cos\varphi_W = 1 - \frac{m^2\cdot l^2\cdot\upsilon_p^2}{2 I_z\cdot M\cdot g\cdot s}\cdot \tag{2}$$

Comparing the above two works a percentage coefficient A_1 is obtained. It defines which part of the energy carried by the bullet is used for the pendulum deflection:

$$A_1 = \frac{W_p}{W_w}\cdot 100\ \%, \text{ or } A_1 = \frac{1-\cos\varphi_p}{1-\cos\varphi_w}\cdot 100\ \%\cdot \tag{3}$$

The determined balance of the ballistic pendulum and the geometric and mass characteristic let to calculate the theoretic pendulum work which would be done if the whole kinetic energy carried by the bullet was changed into it. This work was compared with the real work of pendulum during shooting over the given specimen and determined on the basis of the angle of pendulum deflection. Fig. 7. Illustrates the values of A_1 as a function of the specimen gauge for the 10GHMBA – E620 steel put to shooting over by the B-32 bullet of 12.7 mm caliber.

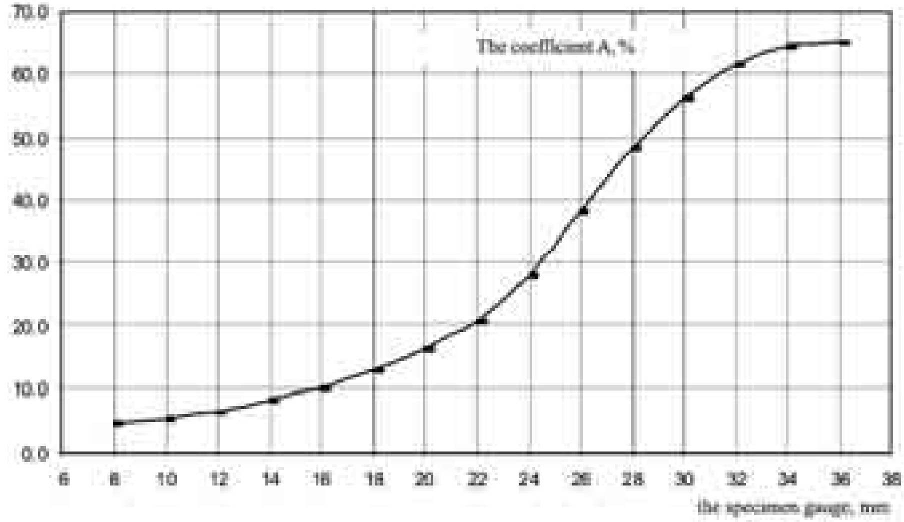

Fig. 7. The values of A_1 for 10GHMBA steel as a function of the specimen gauge

ii. A_2 – the bullet energy, A_3 – the bullet momentum

The coefficient A_2 proportionally defines the kinetic energy which the bullet keeps after moving over the specimen. It is defined by equating the squares of the bullet speeds before and behind the specimen:

$$A_2 = \frac{E_{\text{behind}}}{E_{\text{before}}} \cdot 100\ \%, \text{ or } A_2 = \frac{\upsilon^2_{\text{behind}}}{\upsilon^2_{\text{before}}} \cdot 100\ \%. \tag{4}$$

The coefficient A_3 proportionally defines the momentum which is kept by the bullet after mowing over the specimen. It is defined by equating directly the bullet speed before and behind the specimen:

$$A_3 = \frac{H_{\text{behind}}}{H_{\text{before}}} \cdot 100\ \% \text{ or } A_3 = \frac{\upsilon_{\text{behind}}}{\upsilon_{\text{before}}} \cdot 100\ \%. \tag{5}$$

The values of A_2 and A_3 are presented on Fig. 8.

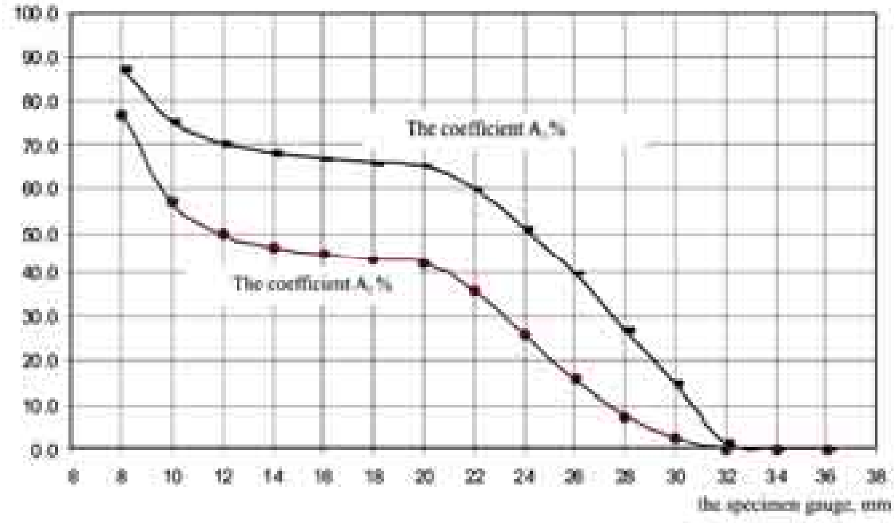

Fig. 8. The values of A_2 and A_3 for the 10GHMBA steel as a function of the specimen gauge

iii. A_4 – the force impulse, A_5 – the angle of the pendulum deflection

The ballistic pendulum is equipped with a dynamometric sleeve directly to which a raked specimen is installed. The sleeve records the impulse of the force which compresses the sleeve during bullet impact. The value of that force increases along with the specimen gauge. For the specimen gauge which stops the bullet, the force is maximum. A_4 expresses the ratio of the recorded force for a given specimen gauge to the force recorder for the specimen which stops the bullet. The angle of the pendulum deflection has a similar run. After overrun the specimen gauge which stops the bullets the value of the angle deflection rises insignificantly. A_5 is a ratio of the pendulum deflection angle to the deflection angle for the specimen which stops the bullet. Both the coefficients are determined from the following dependence:

$$A_4 = \frac{F_h}{F_{\max}}\ ,\ A_5 = \frac{\varphi_h}{\varphi_{\max}}\ . \tag{6}$$

The values of A_4 and A_5 are presented in Fig. 9.

5. Conclusions

The basic goal of making the estimation of penetrating the shield by the bullet is enabling to preliminary define the ballistic resistance of armor by means of resistance characteristics of the material determined by using the static blocking out. The obtained dependences may be useful for calculating the shields made of the tough materials like constructional steels.

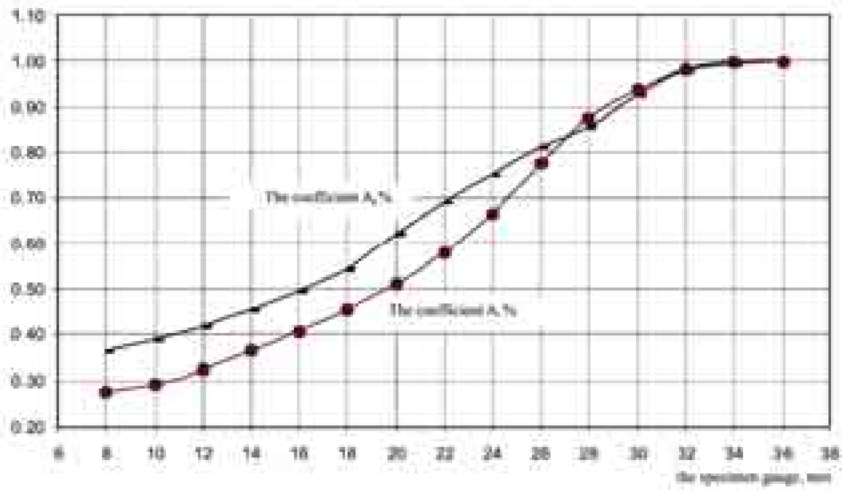

Fig. 9. The values of A_4 and A_5 for the 10GHMBA steel as a function of the specimen gauge

For the 10GHMBA steel, for which the limit of resistance is 758 MPa, the minimum armor gauge stopping the bullet B-32 of 12.7 caliber is 32 mm. The proposed here method relying on defining the values of coefficients on the basis on measuring parameters for estimating the minimum gauge of armor resistant for penetrating can be applied only for strictly chosen bullets. The bullets characteristics have to be equal i.e. the same kinetic energy and geometric quantities as length, diameter, bullet tip, etc. The method has turned out to be useful for the tested steel shields [8].

For few dozen years there have been conducted detailed basic researches concerning the ballistic resistance of the armor shields. Those investigations are based on well-known theorems of continuous medium mechanics, cracking mechanics, on the finite-element method and by means of the computer engineering. Until now those investigations although very valuable from the cognitive point of view have not resulted in creating any practical method for unsophisticated or safety shields designing [10]. For that reason a parallel developing of simple and practical computational methods based on choosing the most essential characteristics of the armor penetrating by bullets seems to be purposeful.

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