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To cite this article: A V Guskov *et al* 2017 *J. Phys.: Conf. Ser.* **919** 012011

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Experimental studies of the physical process for forming the profile of a friction unit in a ballistic installation

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Abstract. In the paper, physical processes were identified and investigated when the device being thrown in a ballistic installation moved. A set of methods for studying the processes that occur during the operation of the friction unit of the device being thrashed was developed. The process of plastic deformation during the formation of a friction unit of a device being thrashed, made of high-carbon steel, was studied. The process of forming a profile on the friction unit was studied, and the influence of the geometric parameters of the profile of the inner surface of the ballistic installation on the specific pressure of the formation of the friction unit of the device being thrown was determined. On the basis of practical experiments, conclusions were drawn about the effect of the geometric parameters of the friction unit profile on the punching force.

1. Introduction

The friction unit is an important element for the development and design of a projectile to be projected in a high-speed ballistic installation. The friction unit of the device being thrashed performs two priority tasks:

- Providing forward and rotational motion of the device being project at the expense of the profile of the inner surface of the ballistic installation;
- Sealing of powder gases.

The process of improving and modernization of the projected device was characterized by the necessity to retain the geometric parameters of the friction unit (diameter, width, and distance from the bottom) and performance properties: the resisting forces of the friction unit and the endurance of the ballistic installation.

When increasing the efficiency of the device, the retention of the properties requires multiple full-scale tests.

2. Goals and objectives of the experiment

Projectile is to identify and study the physical processes that occur when the device is being projected.

In the study, the main physical processes occurring in the ballistic installation during sample throwing were identified:



- Plastic deformation of the material of the friction unit while moving along the profile of the ballistic installation;
- Heat released in the interaction zone of the friction unit of the device being projected and the inner surface of the ballistic installation.

The isolated physical processes occurring during the operation of the friction unit of a missile are common and can be used to study the working capacity and the development of physical principles for designing friction units of missiles of all types, diameters and materials.

The procedure for studying the processes occurring at the stage of plastic deformation of the material of the friction unit of a missile consisted of a complex of experiments:

- Cavity formation on the friction node by the method of biaxial compression;
- Thrusting of the missiles with the friction nodes under investigation through the initial section of the internal profile of the ballistic installation;
- Deformation and destruction of the protrusions on the friction node.

3. Research procedure

The experimental method of biaxial compression based on the stepwise deformation of a rectangular projection of a friction unit of a new type by a punch with a working surface corresponding to the internal profile of a pipe of a typical ballistic installation was used as the primary method for investigating the plastic deformation of the material of the friction unit during incision (forming a depression between the protrusions).

For the formation of the cavity, ring segments with friction nodes made of typical preforms of missiles were used as samples. In addition, standard samples with variants of the friction unit of a new type with various geometries of a single protrusion from blanks of a missile, namely high-carbon steel, were manufactured.

The research consisted of three stages. At the first stage, a range of specific contact pressures q was established for typical friction assembly designs made of the following materials: iron ceramics, copper-nickel alloy and copper. The level of specific contact pressures q was:

- For the iron ceramics 1000-1100 MPa;
- For the Cu-Ni alloy from 1200 to 1280 MPa;
- For copper from 1150 to 1200 MPa.

It is necessary to pay attention to commensurability of the values of the specific contact pressures of the primary reaction of the friction node for the materials under study. The form of the dependence of the specific pressure on the degree of deformation in biaxial compression is shown in Figure 1 and indicates three sections in the formation of the projection.

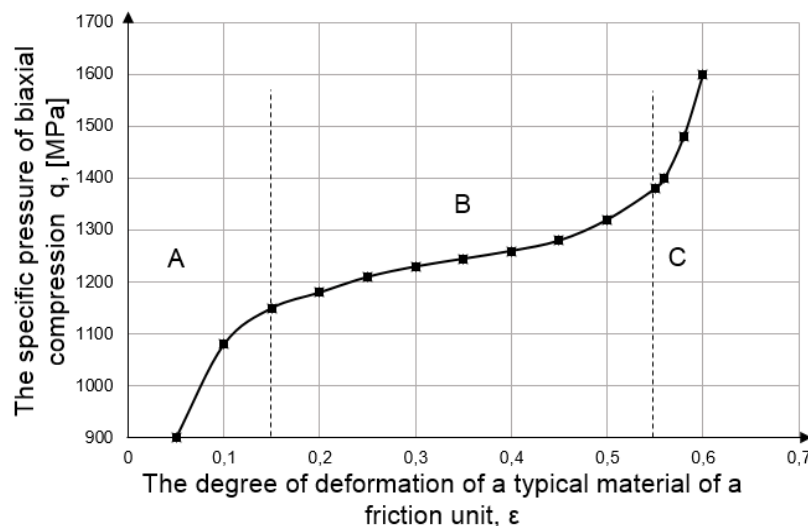


Figure 1. Dependence of the specific pressure of biaxial compression on the degree of deformation of a typical material of a friction unit $q = f(\varepsilon)$.

- Section «A» - the period of selection of gaps in the installation and the elasto-plastic deformation of the material of the friction unit in the range of ε from 0 to 0.15;
- Section «B» - formation of the knot projection at ε from 0.15 to 0.55;
- Section «C» - for $\varepsilon > 0.55$, the deformation of the material compression of the friction unit along the bottom and the cut field with a significant increase in the specific pressure.

A significant increase in the specific pressure in section «C» confirmed the need to limit the coefficient of deformation of the material of the friction unit when designing a new type of friction unit $\varepsilon \leq 0.55$. At the second stage of the research, a series of experiments was performed to establish the dependence of the specific pressure $q = f(\varepsilon)$ on the degree of deformation for the design of the friction unit of a new type. The degree of deformation ε of the protuberance material uniquely determines one of the main parameters of the friction node of a new type - the height of the protuberance, since $h = y_{max}/\varepsilon$. The maximum value of y_i corresponds to the height of the cut of the ballistic installation ($y_{max} = \Delta$). Therefore, to investigate the effect of the degree of deformation ε on an important indicator of the efficiency of a new type of friction unit, the specific contact pressure is necessary in a wide range of variation in the width and height of the single projection. Experiments on biaxial compression were carried out on samples with dimensions of a single protuberance with a width c from 1.4 to 2.0 mm and a height h from 1.8 to 3.6 mm. The value of the specific pressure q according to the method was determined as the ratio of the force on the punch to the actual contact area. The dependences $q = f(\varepsilon)$ (Figure 1) are similar for investigations of ring samples of friction units of a new type with a single projection and correspond to the dependences of the specific pressure on the degree of deformation for the friction nodes.

Only 5 series of samples of friction units of a new type with different ratios h/c of a single projection were tested. The accuracy of the contact pressure assessment is $\pm 8\%$ when the yield strength $\sigma_{0.2}$ of high-carbon steel varies from 350 to 440 MPa.

Based on the results of statistical processing of experiments in the selected range of variation in the degree of deformation ($0.30 < \varepsilon \leq 0.55$), the specific pressure was approximated from the degree of deformation for section «B»:

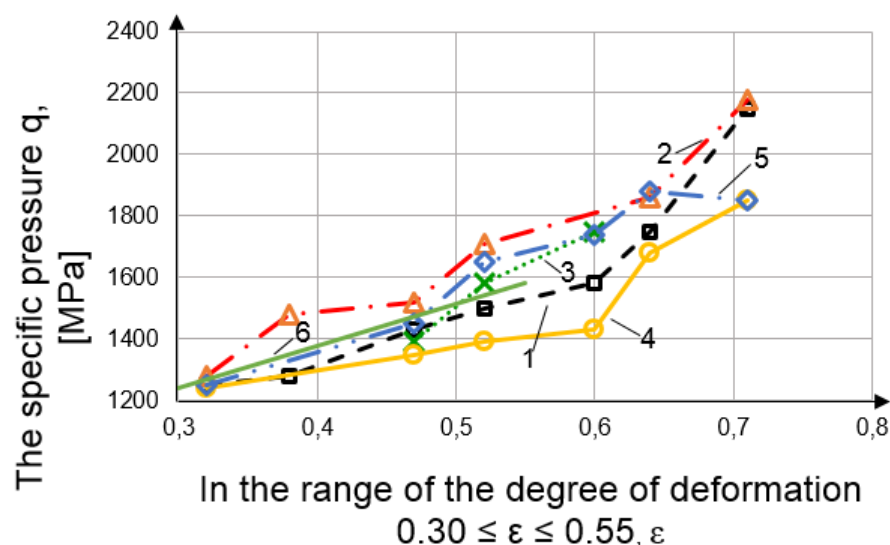


Figure 2. Dependence of the specific pressure in the range of the degree of deformation $0.30 \leq \varepsilon \leq 0.55$ for samples with different geometries of a single projection.

$$q = 1500\varepsilon + 825 \quad (1)$$

On the basis of experimental dependences, an analysis of the magnitude of the operation of a biaxial compression characterizing the energy expenditure on the plastic deformation of the material of the friction unit of the missiles was made. The value of work of the biaxial compression of the single projection AC is about 96 J.

In the third stage, experiments were carried out on the biaxial compression of the single projection of the friction assembly on a specimen 122 mm in diameter. Based on the results of the experiments, the dependence of the force on the penetration depth of the cut was constructed: $P = f(y)$. During processing, the dependence of the specific contact pressure on the degree of deformation $q = f(\varepsilon)$ was obtained.

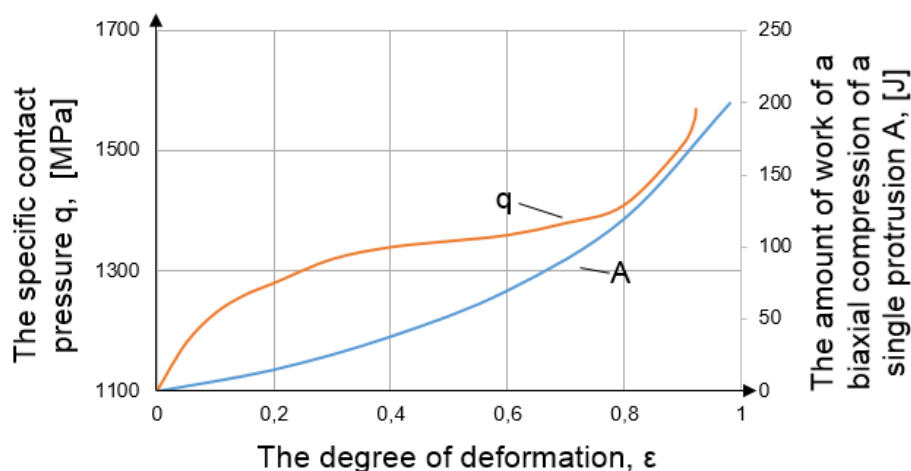


Figure 3. Dependences $q = f(\varepsilon)$ and $A = f(\varepsilon)$ obtained on a single projection of a new type of friction unit.

The shape of the curve $q = f(\varepsilon)$ indicates the presence of a section «B» in the biaxial compression process, in which the specific pressure is linearly dependent on the degree of deformation and corresponds to the dependence $q = 1500\varepsilon + 825(1)$. In this section, the increase in the specific pressure is insignificant with respect to sections «A», «C».

When pressing the working part of the punch into the material of the friction unit, the deformation force increases. The increase in the specific pressure of the material resistance to the plastic flow at the time of completion of the formation of the depression with respect to the specific pressure at $\varepsilon = 0.5$ is 1.23 times.

The second step in the experiment is to determine the loads when the missiles are pushed through the profile of the ballistic installation.

Investigation of the process of plastic deformation of the material of the friction unit of a new type and determination of the punching force was carried out on a section of a profile pipe 122 mm in diameter and with dimensions corresponding to a typical ballistic installation.

The conical part of the tube of the ballistic installation, which performs the function of the stamping tool at the initial moment of motion of the projected sample, consists of a smooth conical part and a conical slope of the rifling. When introducing and sending the projectile, the friction unit is fixed. The obtained compound ensures the preservation of the propellant gases at the initial moment of motion.

The process of forming protrusions on the friction node includes two stages:

- Deformation of the material of the friction unit;
- Formation of protrusions on the friction unit.

To determine the axial force and the distribution of specific pressures, a technique based on experiments at the selected stages was developed. To optimize manufacturing, a batch of samples consisting of three groups was prepared: two groups with friction nodes of a new type with different ratios h/c , a third control group with a copper friction unit.

To determine the dependence of the punching force on the geometric parameters of the construction of a friction unit of a new type, studies were carried out on a batch of samples with a diameter of 45 mm. All samples were made of high-carbon steel.

The dependence of the punching force $P_I = f(c)$ for different hub height h is shown in Figure 4. The value of P_I is inversely proportional to the height of the protuberance h , which essentially depends on the change in the width of the projection c . Thus, for $h = 1 \text{ mm}$, a change in the width of c by a factor of 5 leads to an increase in the force by 6.5 times, and at $h = 2 \text{ mm}$ only in 2.7.

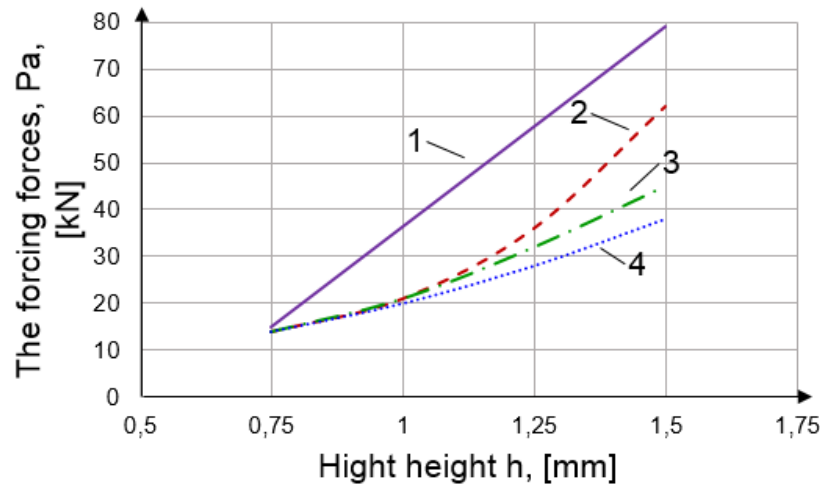


Figure 4. – Dependence $P_I = f(c, h)$

With the range of changes in the c/h ratio from 1.5 to 0.375 (4 times), the axial punching force is significantly reduced from 79.3 to 13.3 kN (about 6 times). This result confirmed that the friction unit of a new type is a design that allows to regulate the interaction force of a node with a ballistic installation by changing the geometric parameters of the projections and the distance between them. In this case, the width of the projection defines the working area of the projection. This must be taken into account when specifying admissible deviations to the size of c when manufacturing the friction unit.

To confirm the results obtained on samples of 45 mm, the extrusion force from the parameters of the friction unit of a new type (h and c), the width B (the number of protrusions) and the diameter D of the friction unit, a pilot batch of 122 mm diameter samples was produced. The protrusion of samples through a section of the profile pipe was carried out in two stages.

At the first stage, a free movement and rotation of the sample occurred in the connecting cone, the cone of penetration. The material yield strength σ_{02} of the missiles varied from 355 to 460 MPa.

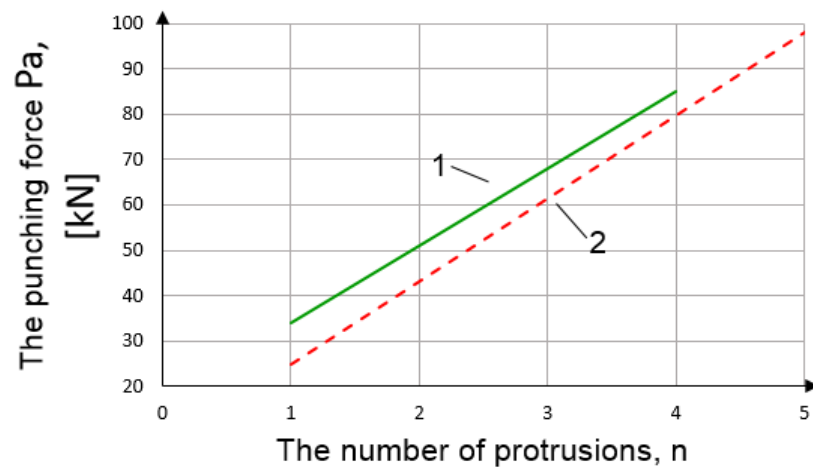


Figure 5. Dependence of the punching force on the number of protrusions

The values of the coefficients at h , c , b , D determined the degree of influence of the corresponding parameter of the friction unit of a new type on the variation of the axial force P_l and confirmed the determining role of the height and width of the protuberance in the interaction of the new type of friction unit with the profile tube of the ballistic installation during the formation of the protrusions.

4. Results and discussion

Research based on the method of biaxial compression made it possible to conclude that the geometric parameters of the friction unit of a new type and the specific pressure necessary to form the protrusion are interconnected by one of the main parameters of the rifled portion of the ballistic installation, the depth of the cut Δ .

The following dependencies are established through the profile when estimating the loading of the missiles to be extruded through the profile:

- The force of extrusion of samples with a new type of friction unit through a pipe with a smooth internal surface is less than 1.7 times the copper nodes;
- The force in the second stage when forming the protrusion exceeds the force at the first approximately 1.55 times for the friction unit of a new type and 2.2 times for the brass.

When the angles of inclination of the front cone of a smooth pipe and the conical slope of the profile pipe are equal, the rolling force is proportional to the pressure in the contact "profile pipe-friction unit", i.e., the specific pressure.

5. Conclusion

According to the results of the experiments (Figure 5), it is determined that the dependencies of the force of extrusion depend on the number of protrusions. With an increase in the number of protrusions, the punching force increases significantly. It has been established experimentally that the width of the projection of the friction unit exerts the main influence on the punching force.

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