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Hot forming hollow products from high strength aluminum alloy with required treatment of metal structure by plastic deformation

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Abstract. *Using the finite element method conducted research of technology and established parameters of hot forming hollow products of alloy V93pch with required treatment of metal structure by plastic deformation to provide the mechanical properties in the wall of product after heat treatment. There are determined by the calculation the shape and dimensions of the initial workpiece, temperature heating deforming die, forming's force, force of pushing the product from matrix, the specific forces on the deforming die, temperature change during forming of the product, stress-strain state in deformed metal, final shape and size of the product. According to the results of modeling designed and manufactured stamp for hot forming and conducted experimental research in a hydraulic press. Submitted stretching's tests of standard samples, that were cut from the wall of the product after the heat treatment. Defined conditional yield strength, strength limit, conditional elongation and hardness. The test data meet the requirements for the mechanical properties of deformed metal in the wall of the product.*

Keywords: hot forming, hollow product, aluminum alloy, finite element method, force mode, strain intensity, experimental research, mechanical properties.

Introduction. Recently, for the manufacture of articles with high reliability and durability during hot forging are standing problems performing the necessary treatment of the metal structure throughout the volume of the product or parts of the volume by plastic deformation. This treatment provides the specified mechanical properties of articles. Methods and thermomechanical parameters of forging on hammers and hot forming on presses of articles from ferrous metals and alloys, including high-strength aluminum alloys are considered in [1]. For operations like setting, drawing, piercing, bending are listed elements of forgings design and design of deforming tool. The focus is on obtaining the required shape of articles. In [2] gave recommendations, and examples of design of technological processes and stamping tooling for forging of articles at different press-forging equipment. Also presented especially hot forging parts of different shapes of non-ferrous alloys. In all the above sources, the information based on the experimental data and production experience, and focuses on achieving the desired shape by hot forming of articles. Virtually no recommendations for forming of pats for achieving the specified mechanical properties in deformed metal.

For the improvement of existing and development of new technological processes of forging are now using computer simulation using the finite element method (FEM). Simulation allows you to set the process parameters and to determine the data for the design of stamping tooling, which do not require rework experimental studies [3,4]. In [5,6] with the FEM computational studies conducted during hot rolling the cylindrical workpieces and forging of axisymmetric workpieces and stamping of axisymmetric details of the required shape. In the sources [7-9] are given the possibility of obtaining by forging and hot stamping the responsible products from steels with the treatment of the structure of the metal by plastic deformation and the achievement of the necessary distribution of deformations in the bulk of products. The authors of these studies have shown that the treatment of structure can be evaluated from the finite distribution of the strain intensity in the deformed workpieces. Relevant tasks are to hold similar computational and experimental researches of hot forging parts of high strength aluminum alloys.

Purpose. Purpose of this work is to define the parameters and development of technology of hot forming of hollow articles made of high-strength aluminum alloy V93pch with a given treatment of the metal structure for all height of the wall by plastic deformation.

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Sketch of hollow articles made of high-strength aluminum alloy V93pch shown in Fig. 1. The article has a removable wall thickness and a bottom part with a constant thickness. In the wall of the product is necessary to provide the given treatment of metal structure by plastic deformation to obtain the required mechanical properties of deformed metal after heat treatment. One of the methods to obtain such products is ironing of the hollow workpiece in a conical die. By selecting the shape of the original workpiece and size of wall thinning in forming by drawing can achieve a desired treatment of metal structure by plastic deformation.

Determining the shape and size of the initial workpiece and parameters of hot forming technology performed by computer simulation using the finite element method and using the program DEFORM. There are subjected to deformation the workpieces of aluminum alloy V93pch, that obtained by injection. Punching interval according to the recommendations of [1] for this alloy is 430°-350°C. The speed of deformation V_0 =7 mm/sec and the friction coefficient μ =0,15 selected from the conditions for further experimental studies on a hydraulic press DB2436 using a lubricant for hot forming at temperatures up to 450°C LOCTITE 8191 on the basis of molybdenum disulphide. By modeling was necessary to set the preheating of the deforming tool to provide the required stamping interval.

The simulation results are given for the specified shape and size of the initial workpiece, which provide the necessary treatment of metal structure by plastic deformation and specified mechanical properties in the wall of the hollow article after further heat treatment. Calculated sizes and shape of the initial workpiece shown in Fig. 2.

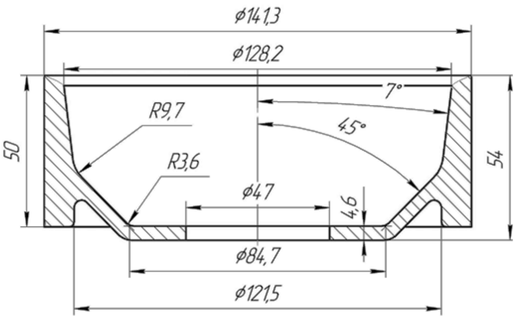


Fig. 1. Sketch of hollow articles made of high-strength aluminum alloy V93pch

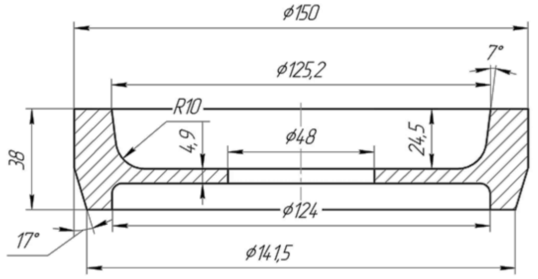
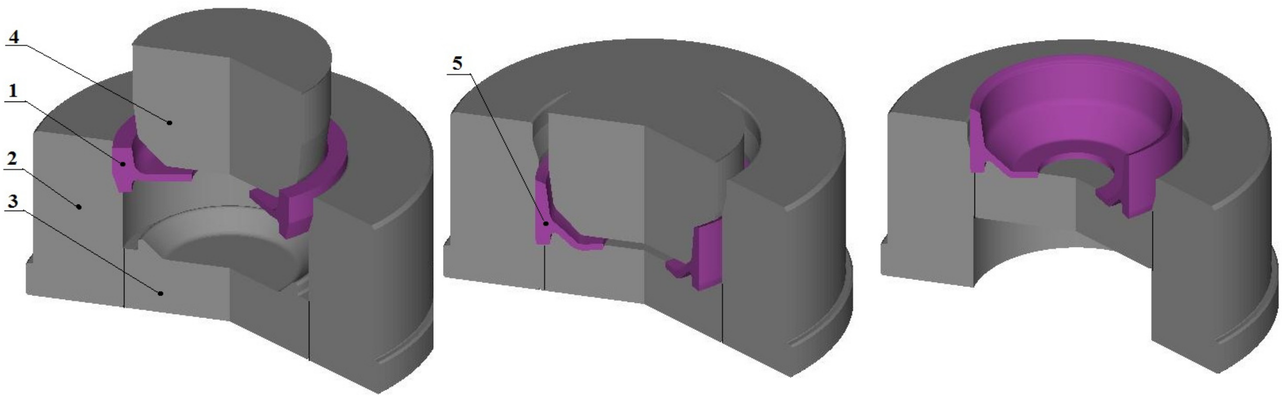


Fig. 2. Calculated sizes and shape of the initial workpiece

The calculated position of the deforming tool in the section shown in Fig. 3. Fig. 3a shows the position at the beginning of forming. The initial workpiece 1 is set in the die 2 with a conical deforming surface for ironing. In the die 2 has a plate 3 for forming the bottom part of the product. Deformation perform by punch 4. Position of the deforming tool at the end of forming shown in Fig. 3b. Move the the punch 4 during forming for obtaining the product 5 is 66 mm. Ejection from the fixed die of product 2 is performed by moving up the plate 3 (Fig. 3c).

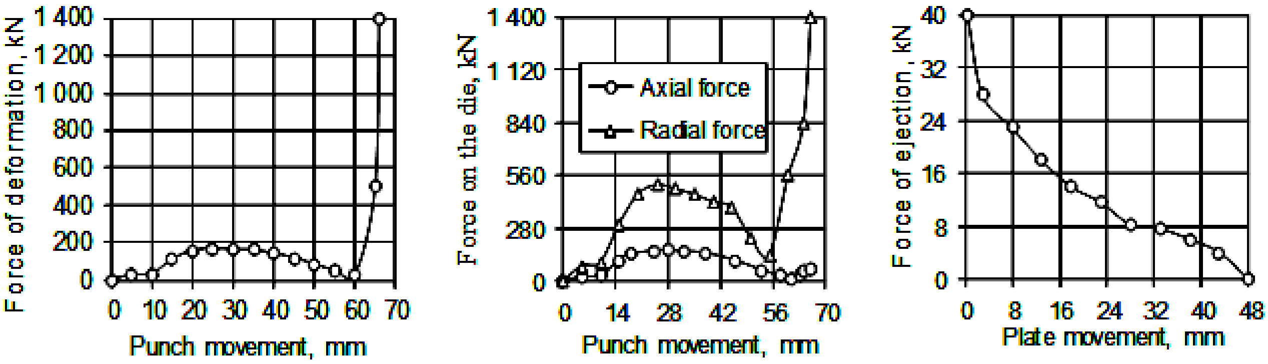


a *b* *c*

Fig. 3. The calculated position of the deforming tool in section during forming: a – at the beginning of stamping, b – at the end of forming, c – after ejection of the product

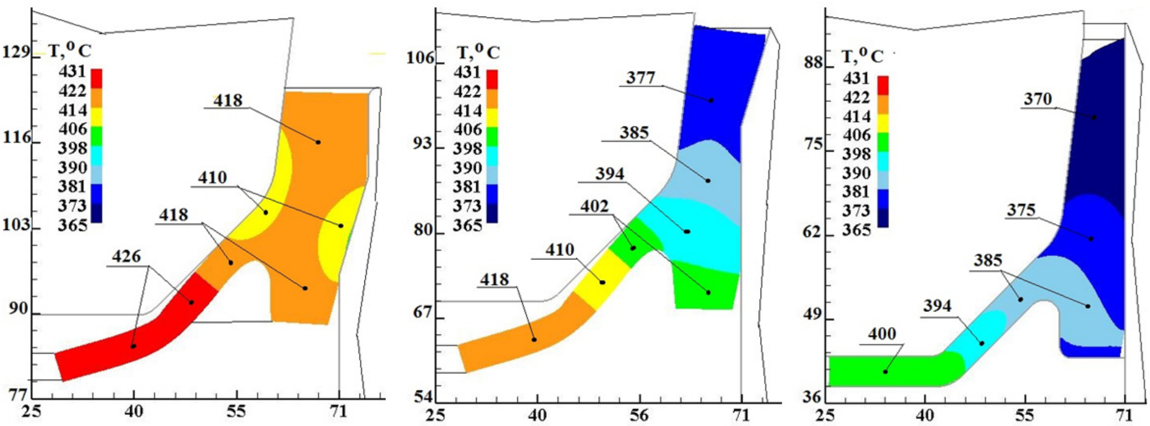
Forming's force modes and ejection of product shown in Fig. 4. Fig. 4a shows the dependence force of deformation of moving the punch. At the stage of forming the workpiece by ironing first increases stress and reaches a maximum value of 180 kN while moving the punch 30 mm, and then the force is reduced to 25 kN at the end of the drawing. Then, the deformation force increases when forming the bottom part of the hollow article starts and reaches 1400 kN at the end of forming. Dependencies axial and radial forces on the die of movement the punch shown in Fig. 4b. First axial force increases and is maximum at 28 mm of movement the punch, and then decreases to a minimum value 19 kN at the completion of ironing and increases to 1390 kN at the end of forming. The dependence of the radial force of the punch movement is similar to the dependence of the deformation force. The force has two peaks. One of them value of 510 kN obtained in step of ironing, and the other - 1400 kN at the end of forming. Modeling also determined the dependence the force of ejection the products from the die of moving the plate after forming (Fig. 4c). The maximum value 40 kN is obtained at the beginning of ejection and then decreasing until the moment of out the product from the die. These data were used in the selection of pressing equipment and designing die equipment.

The sequence of forming the products with a temperature distribution in deformed workpiece shown in Fig. 5. Thin lines indicate the portion of the punch and die. Fig. 5a shows the position when moving the punch is 20 mm. Workpiece is deformed by the conical part of the die and performed the bulging and bending of bridge. During deformation of 3 seconds in the deformed workpiece formed three areas with different temperatures. In the area of the wall temperature decreases from 430° to 410°C, and bridge - to 426°C and 418°C. When moving the punch 40 mm (Fig. 5b) performed the wall thinning and increasing the height of deformed workpiece. At the same time bridge is almost not deformed. In the area of bridge temperature decreases to 402°C÷418°C. The deformed wall's temperature of the workpiece changes from a value 377°C at the top part, to 402°C at the bottom part. In the final step of forming the wall does not deform, but performed the forming of bottom part of hollow article. The temperature distribution at the end of forming shown in Fig. 5c. The temperature during the deformation 9.4 seconds in wall decreased to values in the range 370°C÷385°C, and in the area of bridge – to 385°C÷400°C. Thus forming temperature range observed during forming of hollow article.



a *b* *c*

Fig. 4. Forming's force modes and ejection of product: a – dependence force of deformation of moving the punch, b – dependencies axial and radial forces on the die of movement the punch, c – dependence the force of ejection the products from the die of moving the plate



a *b* *c*

Fig. 5. Sequence of forming the products with a temperature distribution in deformed workpiece: a – moving the punch is 20 mm, b – moving the punch is 40 mm, c – moving the punch is 66 mm. The dimensions on the axes in millimeters

The treatment of the metal structure by plastic deformation is possible to estimate by distribution of the intensity of deformation ε_i in terms of the product after forming, which is shown in Fig. 6. It was obtained from the height of the wall: ε_i =0,26 in the lower part and ε_i =0,45÷0,64 in a remaining bulk of the wall. In the area of bridge the intensity of deformation is between ε_i =0,26÷0,46.

For the design of stamping tooling is necessary to have a specific allocation of force into deforming tool. Fig. 7 shows the distribution of the normal stresses on the surfaces of the punch and die which are in contact with the deformed workpiece and appear at maximum force of forming. Maximum of these stresses is 160 MPa on the punch, on the die – 120 MPa.

By results of modeling is designed and manufactured for hot forming stamp. Construction and photo of stamp on a hydraulic press DB2436 with 4MN force are shown in Fig. 8. Construction of stamp is shown in Fig. 8a. The stamp consists of a bottom plate 1 a round shape and grooves for mounting on the press table, in which installed the plunger 2. On the bottom plate 1 is placed die 3 and plate 4 with the guide ring 5. Die 3 fixed by ring 6 and bolts 13. The punch 7 is located in the punchholder 8. Punchholder 8 fixes the punch 7 with base plate 9 to an intermediate plate 10 by bolts 14. In the intermediate plate 10 screwed four studs 11. On studs set upper plate 12 and secured by bolts 15. Photo of stamp on a hydraulic press DB2436 is shown in Fig. 8b.

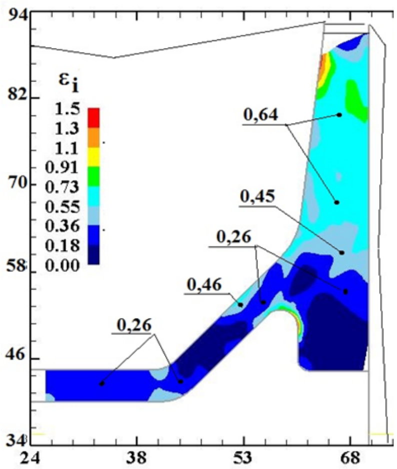


Fig. 6. Distribution of the intensity of deformation ε_i in terms of the product after forming. The dimensions on the axes in millimeters

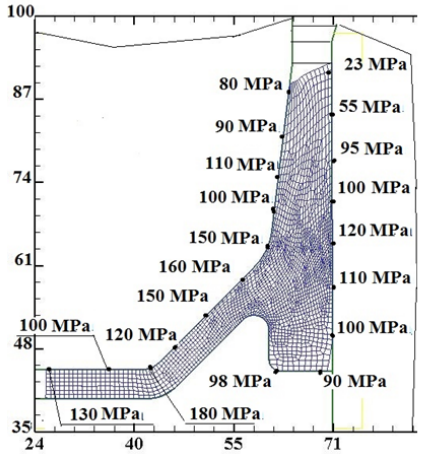
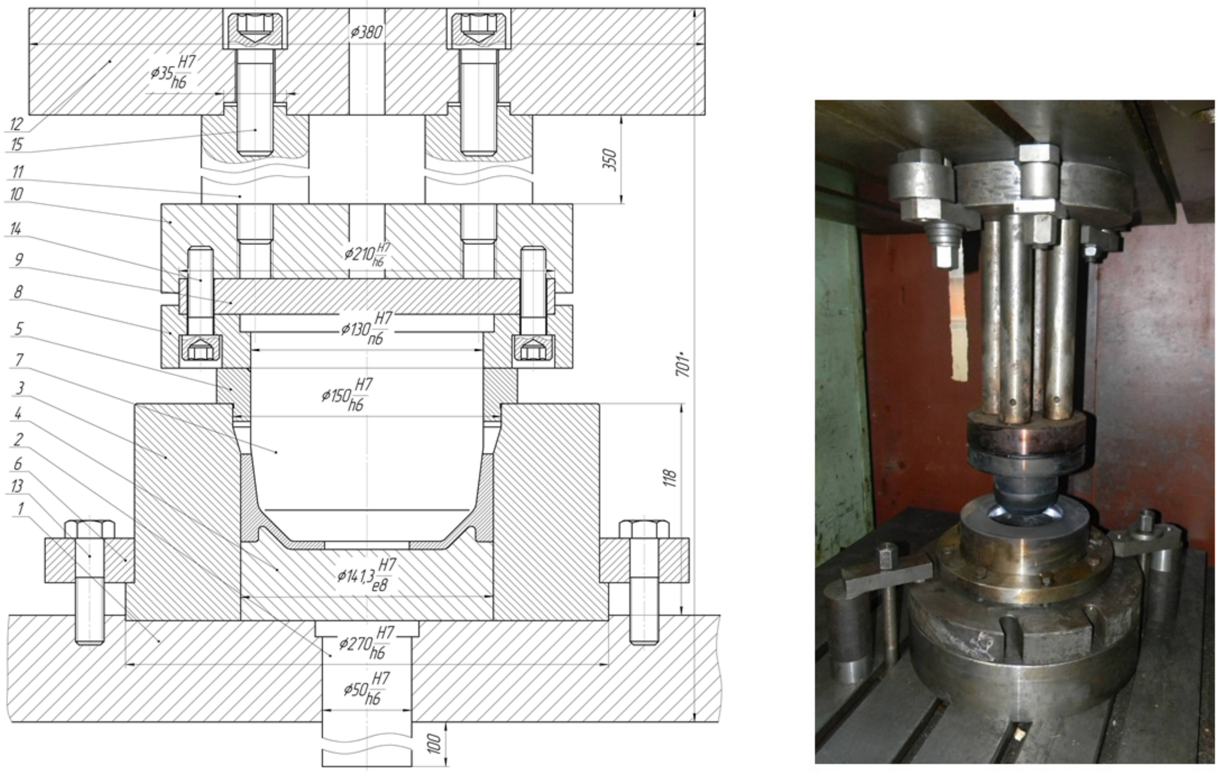


Fig. 7. The distribution of the normal stresses on the surfaces of the deforming tool, which appear at maximum force of forming. The dimensions on the axes in millimeters



a *b*

Fig. 8. Construction of stamp (a) and photo of stamp on a hydraulic press DB2436 (b)

Before stamping, in accordance with the calculated data, the punch 7, the die 3 and the plate 4 heated to 360°C by the gas burner. The initial workpiece coated with lubricant LOCTITE 8191 warmed up in an oven to 430°C and installed into the die 3. During the move of press's slider down occurs forming of hollow product. The experimental value of the deformation's force 1298 kN was determined by the pressure gauge of the press. The discrepancy with the calculated value was 8%. The initial workpiece and the product after hot forming shown in Fig. 9. Fig. 9a shows a photo of the initial workpiece. View of product from the hollow shown in Fig. 9b. Fig. 9c is a view of the product from the bottom part.

As mentioned above, except that the shape and dimensions of the product, it was necessary to obtain predetermined mechanical properties in the wall of the product. After forming was performed the heat treatment of product, the essence of which consisted in hardening and artificial aging. For the tensile test, three standard samples were cut from the product wall. The table shows the test results of the strength limit ($\sigma_{\hat{a}}$), conditional yield strength ($\sigma_{0,2}$), relative elongation (δ) and hardness (HB). The table also shows the data according to the drawing requirements. The results are consistent with the specified requirements.

а *б* *в*

Fig. 9. The initial workpiece and the product: a – initial workpiece, b – view of product from the hollow, c – view of the product from the bottom part

Table

Mechanical properties of the deformed metal

№ specimen	Mechanical properties			
	$\sigma_в$, MPa	$\sigma_{0,2}$, MPa	δ , %	HB
1	510	480	4,1	152
2	510	470	4,3	155
3	510	470	4,1	152
Drawing requirements	Not less than 480	Not less than 440	Not less than 4	Not less than 125

Conclusions. Modeling by finite element method were determined parameters of hot forming the hollow product of aluminum alloy V93pch with required treatment of metal structure by plastic deformation to provide the mechanical properties in the wall of product after heat treatment. By modeling were determined the shape and dimensions of the initial workpiece, temperature heating of the deforming tool, forming's force, the force of ejection the product from the die, the normal stresses on the deforming tool, temperature change of metal during forming, the stress-strain state of workpiece, the final shape and dimensions of the product. According to the results of the settlement analysis is designed and manufactured stamp for hot forming and experimental studies on a hydraulic press. Submitted tensile tests of standard samples that are cut from the wall of the product after the heat treatment. There are identified relative yield strength, strength limit, relative extension and hardness. The test data meet the requirements of the mechanical properties of the metal in the wall of the article.

Гаряче штампування порожнистих виробів із високоміцного алюмінієвого сплаву з заданим пропрацюванням структури металу пластичною деформацією

В.Л. Калюжний, В.М. Горностай, О.О. Гулюк, Я.С. Олександренко

Анотація. *Методом скінченних елементів проведено дослідження і встановлені параметри технології гарячого штампування порожнистого виробу зі сплаву В93пч із заданим пропрацюванням структури металу пластичною деформацією для забезпечення механічних властивостей в стінці виробу після термообробки. Розрахунковим шляхом визначені форма і розміри вихідної заготовки, температура підігріву деформуючого інструменту, зусилля штампування, зусилля виштовхування виробу з матриці, питомі зусилля на деформуючому інструменті, зміна температури металу при формоутворенні виробу, напружено-деформований стан в здеформованому металі, кінцеві форма і розміри виробу. За результатами моделювання спроектований і виготовлений штамп для гарячого штампування і проведені експериментальні дослідження на гідравлічному пресі. Виконано випробування на розтягнення стандартних зразків, які вирізані з стінки виробу після проведеної термообробки. Визначені умовна межа текучості, межа міцності, відносне подовження і твердість. Дані випробувань відповідають вимогам за механічними властивостями здеформованого металу в стінці виробу.*

Ключові слова: *гаряче штампування, порожнистий виріб, алюмінієвий сплав, метод скінченних елементів, силові режими, інтенсивність деформацій, експериментальні дослідження, механічні властивості.*

Горячая штамповка полых изделий из высокопрочного алюминиевого сплава с заданной проработкой структуры металла пластической деформацией

В.Л. Калюжный, В.Н. Горностай, А.А. Гулюк, Я.С. Олександренко

Аннотация. *Методом конечных элементов проведены исследования и установлены параметры технологии горячей штамповки полого изделия из сплава В93пч с заданной проработкой структуры металла пластической деформацией для обеспечения механических свойств в стенке изделия после термообработки. Расчетным путем определены форма и размеры исходной заготовки, температура подогрева деформирующего инструмента, усилие штамповки, усилие выталкивания изделия из матрицы, удельные усилия на деформирующем инструменте, изменение температуры металла при формообразовании изделия, напряженно-деформированное состояние в сдеформированном металле, конечные форма и размеры изделия. По результатам моделирования спроектирован и изготовлен штамп для горячей штамповки и проведены экспериментальные исследования на гидравлическом прессе. Выполнены испытания на растяжение стандартных образцов, которые вырезаны из стенки изделия после проведенной термообработки. Определены условный предел текучести, предел прочности, относительное удлинение и твердость. Данные испытаний отвечают требования по механическим свойствам сдеформированного металла в стенке изделия.*

Ключевые слова***:*** *горячая штамповка, полое изделие, алюминиевый сплав, метод конечных элементов, силовые режимы, интенсивность деформаций, экспериментальные исследования, механические свойства.*

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