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Matiukhin A. Candidate of Technical Sciences, Associate Professor, Head of the Department of Metal Forming of National University Zaporizhzhia Polytechnic, Zaporizhzhia, Ukraine, *e-mail: matiukhin85@gmail.com*, ORCID: 0000-0002-2261-0577

Marcin Knapiński Dr hab. inż., prof. PCz, Politechnika Częstochowska, Wydział Inżynierii Produkcji i Technologii MateriałówKatedra Przeróbki Plastycznej i Inżynierii Bezpieczeństwa - zniesiona Częstochowa, Poland, *e-mail: marcin.knapinski@pcz.pl*, ORCID: 0000-0001-8817-2250

Ben A. Senior Lecturer of the Department of Metal Forming of National University Zaporizhzhia Polytechnic, Zaporizhzhia, Ukraine, *e-mail: benanna1985@gmail.com*, ORCID: 0000-0002-9765-8030

MAIN STAGES OF DESIGNING RESOURCE-SAVING TECHNOLOGIES FOR INGOT DEFORMATION ON HYDRAULIC PRESSES

Objective. *To study the technological process of forging large ingots on hydraulic presses in order to identify and reduce resource consumption.*

Research methods. *A finite element method that makes it possible to assess the stress-strain state of a workpiece, the possibility of levelling it, and homogenising it by controlling the factors that form the optimal forging method for a given workpiece.*

Results. *A resource-saving technological process based on the optimal forging method has been developed, which allows to bring the quality of the designed products to a new level and leads to an increase in technical and economic indicators of production. By controlling the stress-strain state of the metal, high quality forged products can be achieved and resource-saving technologies for forging forgings of high-alloy steel grades and alloys can be created.*

Scientific novelty. *The factors that form the rational resource-saving technological process of plastic deformation and the method of forging large forgings from alloyed, stainless steels and alloys on hydraulic presses, as well as the directions of their optimisation, have been formed. The finite element method allows us to predict the distribution fields of the workpiece's stress-strain parameters, metal microstructure, and grain size.*

Practical value. *Practically grounded recommendations for optimal modes of forging ingots from tool steel grades were developed. This will reduce energy consumption, save time in the production of forged products and generally intensify the process of plastic deformation. The proposed recommendations can be applied not only in the processes of forging tool steel grades but also in other types of hot plastic deformation of metals of a wide range.*

Key words: *hot rolling, ingot, tool geometry, flat strikers, notched strikers, numerical modelling, finite element method.*

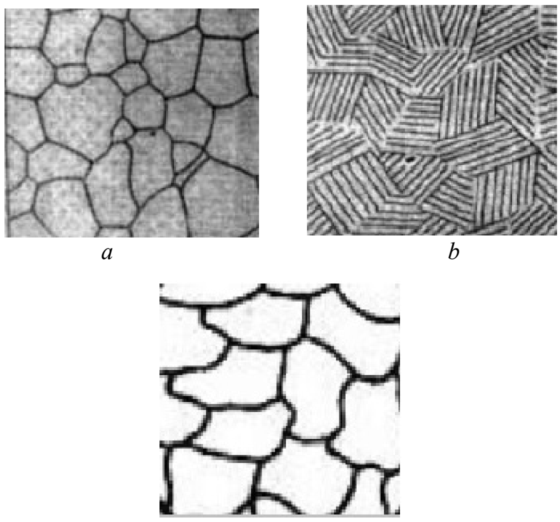
Introduction

The development of a forging process involves the technologist solving two important tasks: ensuring the quality of the product (forging) and ensuring the quality of the process of producing the forging, i.e. selection and development of the optimal forging method for a given product, which includes a combination of billet and tool shape factors, kinematic factor, temperature and structural factors.

Analysis of research and publications

Carbon and alloyed tool steels of the pearlite and ferrite class (Fig. 1*a*, *b*) have high ductility, i.e., the degree of shear deformation. High-alloyed heat-resistant steels, especially austenitic steels (Fig. 1*c*), unlike tool steels, have lower deformability due to a decrease in their ductility [1–3], which depends on the following factors (Fig. 2):

- the presence of slip hindrances: limitation or inhibition of intra- or intergranular deformation;
- the presence of two or more structural components with different properties;
- weakening of the intercrystalline bond at hot plastic deformation temperatures.



a *b* *c*

Figure 1. Scheme of the microstructure of steels:
a – ferrite; *b* – pearlite; c – austenite

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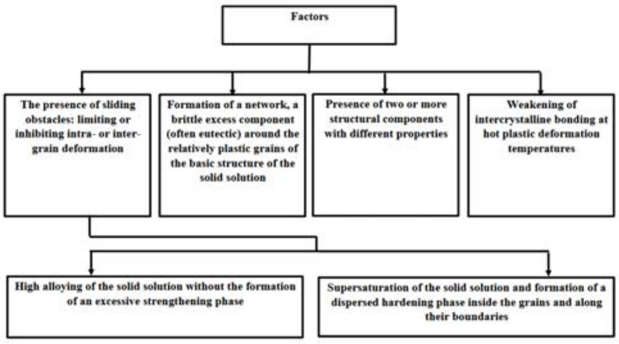

Figure 2. Factors affecting the ductility of high-alloy steels in forging

One thing remains constant: the quality of finished forging products is directly affected by the stress-strain state of the metal. Thus, knowing how to control the stress-strain state of metal, it is possible to achieve high quality forged products and create resource-saving technologies for forging forgings of high-alloy steel grades and alloys.

Purpose of the work

The aim of the study is to investigate the technological process of forging large ingots on hydraulic presses in order to identify and reduce resource consumption. To do this, the issues of improving the economic performance of the technological process, as well as increasing the efficiency of resource use by reducing material waste during forging, energy consumption, and maximising the forging dimensions to the product dimensions are addressed.

Material and research methods

Standard methods for calculating the tasks of metal forming were used in this study, including a comparative analysis of different forging methods, including a combination of billet and tool shape factors, kinematic factors, temperature and structural factors. The application of the finite element method is described.

Research results

The algorithm for developing a forging process is as follows: the first stage involves collecting and analysing the initial data on the final product. This involves analysing the product drawing, material type, production programme and technical requirements for the product in accordance with the technical specification and regulatory requirements. The second stage is to draw up a drawing of the forging according to the recommendations of GOST 7062-90 or regulatory documents in force at the enterprise, indicating forging allowances. The process engineer must determine the material group, whether the material in question is low-ductile or ductile, which will determine the choice of the forging scheme. Having data on the group of forgings and the type of material, it is necessary to select the shape and dimensions of the initial billet (ingot).

The choice of ingot type is determined by the type of forgings, technical specifications and is based on production experience, economic feasibility, and technological capabilities of production. After the ingot is selected, the existing technological solutions implemented at the production site are analysed and the results of this technology are checked for compliance with the requirements of the technical specification.

Next, it is necessary to highlight the features of the forging shape to determine the number and sequence of forging operations (rolling, depositing, landing, drawing, transferring, acceleration, smoothing (ticketing), stitching, rolling, forging welding, separating operations), the purpose of the forging scheme, i.e. what tool will be used for forging, what transitions, crimping, and edging are required. For cylindrical billets, the main forging operation is broaching. Depending on the ductility of the steel or alloy, different strikes can be used for broaching.

In the production environment of many enterprises, technologists face problems with crack formation, unforged parts, coarse grain, geometry deviations from the specified geometry and other defects caused by the instability of the process output under the thermomechanical mode used. It is important to identify and reduce the negative impact on product and process quality of a specific factor, such as uneven temperature field or deformation heating temperature. Controlling the temperature field of the workpiece during forging also allows you to influence the stress-strain state of the workpiece and the microstructure of the metal. The billet can have a different type of temperature field: a homogeneous temperature field, a heterogeneous symmetrical field with a different type of temperature distribution across the cross-section, and a heterogeneous asymmetrical field.

Increasing the dimensional accuracy and reducing the final dimensional error is possible by increasing the time of additional forging operations such as smoothing, ticketing, and hammering, which takes more than 40 % of the main forging time.

High-alloy steels and alloys have the following features during pressure treatment: high hardening at high temperatures; pronounced heterophase structure; high deformation resistance; low strength (especially at high temperatures) of intercrystalline bonds at crystal boundaries in the presence of harmful impurities (sulphur, lead, antimony, tin, etc.) that dramatically reduce ductility and increase brittleness.), which sharply reduce the ductility and increase the brittleness of steels; the absence of phase recrystallisation during forging and heat treatment; low thermal conductivity, which requires special heating conditions, etc. High-alloyed heat-resistant steels and alloys must be forged in a single-phase state, as the homogeneous structure results in more uniform deformation of individual crystals. In fact, the metal of ingots of this type of steel at forging temperature in most cases has a heterogeneous structure, which is characterised by significant irregularities. The required metal structure in these steels is achieved by forging conditions.

Recommendations for the selection of strikers and forging modes are given in [2]. For example, the use of flat forgings (Fig. 3*a*) can cause the appearance of a tensile stress zone in the axial part of the forging, which, in turn, creates a negative stress state of the metal and can lead to

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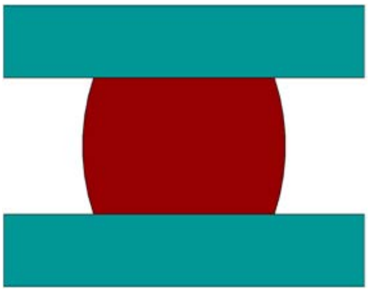
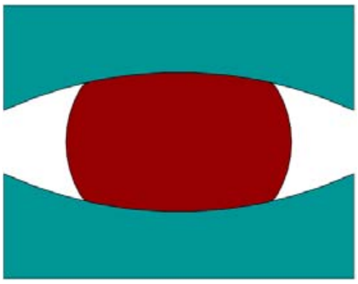
cracks and tears. The conditions in the notched radial forgings with a coverage angle of 120° (Fig. 3*b*) are quite favourable, characterised by a small tensile stress zone.



a



b

Figure 3. Forging strikes:
a – flat; *b* – radial cut-outs

After the tool is selected, it is necessary to determine the thermomechanical forging regime, i.e. the forging temperature interval, the number of intermediate heating of the workpiece (one or more times, depending on the complexity and size of the forging, taking into account the heredity of steel grain size - hereditary fine-grained and hereditary coarse-grained steels are distinguished).

If there are technological solutions available that have proven to be fully satisfactory, the process is designed based on this technology. If the existing technology does not produce the desired result, a series of studies must be carried out to determine the optimal forging method. Forging must ensure a directional fibrous macrostructure and fine microstructure with maximum homogeneity.

For this purpose, after determining the forging scheme, tool dimensions and thermomechanical forging conditions, it is necessary to determine the rheology of the material for further research. The rheology is specified in the form of metal flow curves for different temperature and speed conditions and plasticity diagrams. The rheology of a material can be determined experimentally from tensile, compression and torsional tests, and theoretically. The theoretical construction of metal flow curves is carried out by modelling and is based on the use of reference data on the material and the use of a minimum amount of experimental data [3].

It is advisable to perform the modelling by the finite element method using the Qform software with an assessment of the stress-strain state of the billet, the possibilities of its levelling, and homogenisation by controlling the factors that form the optimal forging method for a given billet. (Fig. 4) The results obtained by modelling forging processes using the Qform software differ from the results of physical experiments by 10–15 % [4]. The finite element method allows us to predict the distribution fields of the parameters of the stress-strain state of the workpiece, the microstructure of the metal, and the grain size.

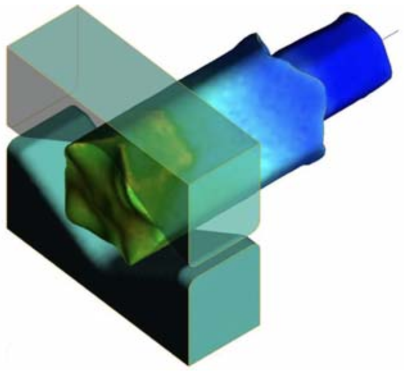


Figure 4. Simulation of the ingot forging process

The finite element method determines not only the change in the shape of the workpiece during deformation, but also the formation of defects (drawbars, non-filling of corners during stamping) and violation of material continuity. In [3], a mathematical model of rheological properties for heat-resistant alloys KhN56VMTYu (EP199) and KhN62VMTYu (EP708) was built using the finite element method, and the stress-strain state of rod forgings made of 12X18H10T steel produced at PJSC Energomashspetsstal using the existing technological process of forging on a high-speed press with a force of 16 MN was assessed. It was found that the use of flat strikers for most of the drawing process and a relatively small amount of forging heating creates an unfavourable stress-strain state of the metal. It was proposed to use notched strikers during broaching, as well as to increase the number of forging heating.

When developing ingot forging technology, great attention is paid to the accuracy of geometric dimensions, which in turn affect the amount of allowances for further machining. Thus, an increase in dimensional accuracy leads to an increase in metal utilisation and savings by reducing the amount of waste. However, increasing dimensional accuracy and reducing the final dimensional error is possible at the expense of increasing the time of additional forging operations such as smoothing, ticketing, and corner knocking, which takes more than 40% of the main forging time. Thus, this means an increase in the time of unproductive use of the rated capacity of the press. The solution to this problem is provided in UA patent No. 48451 [4] and consists in using a rolling stand to calibrate the transverse dimensions of the forging. Thus, reducing the forging size by the final dimensional error of 14–15 mm with an average billet length of 4 m for 4X5MFS and 4X5M3F steel leads to a reduction in waste from 555 kg to 283 kg, i.e. 1.96 times. The machining time for tool steel bar deburring and turning, which is 11.61 hours, is reduced by one third. Thus, labour productivity increases by about 30–40 %.

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Conclusions

The main stages of designing the technology of ingot deformation on hydraulic presses and ways to improve the energy efficiency of the forging process were analysed. These include the following measures:

- change of tool geometry or optimal combination of tools of different geometries,
- transferring auxiliary plastic deformation (smoothing) operations from the forging complex to the rolling stand to increase the equipment's capacity utilisation rate. The rolling stand can be installed in the same line as the forging complex. Rolling in the rolling stand will significantly reduce machining allowances, which in turn will significantly increase the productivity of the accessory sections and the yield of usable products,
- reducing the time for taking metal out for forging (organisational measures – clear procedures, manipulators),
- accounting for the internal heating temperature due to the heat generated during deformation and heating of the ingot (billet) for forging,
- mathematical modelling of the forging process based on the criterion of the impact of the speed and degree of deformation on the structure (grain) of steel, elimination or reduction of surface defects (cracks) and, accordingly, increase in the yield of usable metal products.

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ОСНОВНІ ЕТАПИ ПРОЕКТУВАННЯ РЕСУРСОЗБЕРІГАЮЧИХ ТЕХНОЛОГІЙ ДЕФОРМАЦІЇ ЗЛИВКІВ НА ГІДРОПРЕСАХ

Матюхін А. Ю. — канд. техн. наук, доцент, завідувач кафедри обробки металів тиском Національ-ного університету «Запорізька політехніка», м. Запоріжжя, Україна, *e-mail: matiukhin85@gmail.com*, ORCID: 0000-0002-2261-0577

Марчин Кнапінські — д-р техн. наук, проф., Ченстоховський політехнічний університет, факультет інженерії виробництва та технології матеріалів, кафедра «Переробки пластмас та інженерії безпеки», м. Ченстохова, Польща, *e-mail: marcin.knapinski@pcz.pl*, ORCID: 0000-0001-8817-2250

Бень А. М. — старший викладач кафедри обробки металів тиском Національного університету «Запорізька політехніка», м. Запоріжжя, Україна, *e-mail: benanna1985@gmail.com*, ORCID: 0000-0002-9765-8030

Мета роботи. *Дослідження технологічного процесу кування крупних злитків на гідропресах з метою виявлення та зниження ресурсовитрат.*

Методи дослідження. *Метод скінченних елементів, що дає можливість оцінки напружено-деформованого стану заготовки, можливості його вирівнювання, гомогенізації за рахунок керування факторами, що формують оптимальний спосіб кування для даної заготовки.*

Отримані результати. *Розроблено ресурсозберігаючий технологічний процес, заснований на оптимальному способі кування, що дозволяє вивести на новий рівень якість проектованої продукції і призводить до підвищення техніко-економічних показників виробництва. Шляхом керування напружено-деформованого стану металу можна досягти високої якості кованих виробів та створити ресурсозберігаючі технології процесу кування поковок високолегованих марок сталей та сплавів. Метод скінченних елементів дозволяє спрогнозувати поля розподілу параметрів напружено-деформованого стану заготовки, мікроструктуру металу, розмір зерна.*

Наукова новизна. *Сформовано фактори, що формують раціональний ресурсозберігаючий технологічний процес пластичної формозміни і спосіб кування великих поковок з легованих, нержавіючих сталей і сплавів на гідропресах, і напрямки їх оптимізації.*

Практичне застосування. *Розроблені практично обґрунтовані рекомендації щодо оптимальних режимів кування злитків з інструментальних марок сталей. Це дозволить зменшити витрати енергоносіїв, заощадити час виробництва кованої продукції та в цілому інтенсифікувати процес пластичної формозміни. Запропоговані рекомендації можуть бути застосовані не лише в процесах кування інструментальних марок сталей але й при інших видах гарячої пластичної деформації металів широкої номенклатури.*

Ключові слова: *гаряче прокатування, злиток, геометрія інструменту, плоскі бойки, вирізні бойки, чисельне моделювання, метод скінченних елементів.*

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