Journal of Chemical Technology and Metallurgy, 51, 4, 2016, 393-400

FORGING OF SHAFTS, DISCS AND RINGS FROM BLANKS WITH INHOMOGENEOUS TEMPERATURE FIELD

Igramotdin Aliev[1], Yaroslav Zhbankov[1], Sergey Martynov[2]

[1] *Donbass State Engineering Academy, Shkadinov str. 72, Kramatorsk, Ukraine*
[2] *JSC «Ruspolimet», 1 Vosstaniya Street, Kulebaky, Russia*
E-mail: igram-aliev@mail.ru

Received 24 November 2015
Accepted 27 April 2016

ABSTRACT

The aim of this work is to determine the effect of temperature mode of forging of details such as shafts, discs and rings on the parameters of stress-strain state (SSS) of the workpiece in the process of broaching, upsetting, and expansion. Methods of forging of rings, discs and shafts from billet with non-uniform temperature field were proposed. The processes of forging, which showed the effectiveness of a SSS control of the workpiece temperature field were studied. In the process of forging of rings with the use of a smooth mandrel and a flat die is possible to obtain profiled rings only due to the inhomogeneous temperature field in the workpiece. In the process of forging of the disks by upsetting, also using a flat die, it is possible to obtain forgings of complex shape.

Keywords: *forging, temperature field, strain, deformation, FEM, simulation.*

INTRODUCTION

Products for critical applications used in heavy and power engineering, are produced by forging from ingots. This type of processing allows to fabricate large details of high quality. The bulk of the product range is obtained by forging shafts, discs and rings. Form changing operations for these types of products are broaching by dies to the shaft, upsetting for discs and expansion for rings [1, 2]. A direct impact on the quality of the final product is also caused by such factors as the shape of the tool and thermomechanical forging mode [3, 4].Many studies specifically devoted to study the effect of tool shape and mode of deformation on the parameters of the stress-strain state (SSS) of the workpiece in forging processes. However, due attention of the influence of temperature field on these parameters is not given neither in domestic nor in foreign literature. This is primarily due to the complexity of the calculation of the heat problem by engineering methods popular in recent times. The development of modern calculation methods such as finite element method, can significantly extend the computational capabilities. In this regard, the study of the influence of the temperature field on the parameters of the SSS of the workpiece in the major processes of forging of large forgings is actual.

The aim of this work is to determine the effect of temperature mode of forging of details such as shafts, discs and rings on the parameters of stress-strain state (SSS) of the workpiece in the process of broaching, upsetting, and expansion. Some research is dedicated to forging shafts from blanks with cooled surface [5 - 6] and the upsetting of rapidly heated ingots [7]. These studies do not allow to evaluate fully the impact and to identify opportunities for inhomogeneous temperature field in forging process of large forgings. Therefore, further research in this direction is needed.

COMPUTER SIMULATION OF VARIOUS FORGING MODELS

Ring rolling

Method of forging of profiled workpieces by ring rolling on mandrel using common forging tool was developed. The method involves creation in the workpiece inhomogeneous temperature field so that the inner part of ring has a temperature below the temperature of the outer part. In the process of rolling with deformation of the flat die, the main deformation will be concentrated in the part of the workpiece, which has an increased temperature. The inner part ring will be deformed minimally, because the metal has higher mechanical properties. As a result of such deformation of the workpiece, the shape of the billet will be in the form of a ring with an external hub (Fig. 1). Thus the main influence on the form changing will have the temperature field and the size of the workpiece.

FEM-simulation of the deformation of the billet with inhomogeneous temperature field was done. The simulation was performed in several stages. In the first stage was simulated the cooling process of the inner part of the heated annular blank. The initial temperature of the workpiece was 1100°C, the temperature of the internal surface of the workpiece - 600°C. The cooling was carried out on different workpieces during the various time to ensure the various temperature fields (field 1, field 2). Thus, it was achieved temperature fields with different thicknesses of the homogenized layers. The inner diameter of the rings was 600 mm, outside diameter - 1400, 1640, 1880 mm. The workpiece material is steel 35.

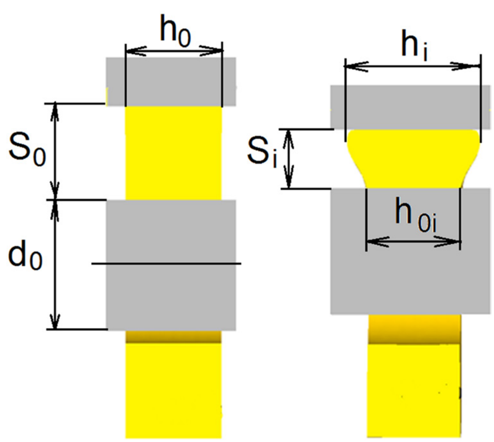

Fig. 1. Scheme of process of billet expansion with inhomogeneous temperature field.

In works [8, 9] a comparison of temperature fields obtained in the workpiece by simulation by the program Deform 3D and experimentally under production conditions was performed. The comparison showed minimum deviation, indicating greater calculation adequacy.

In the second stage the modeling of process of billet expansion with inhomogeneous temperature field was produced. The deformation produced on a cylindrical mandrel with a diameter of 550 mm, flat die of a width of 600 mm. At least 3 pressures on the periphery of the workpiece were produced.

On the first and on the second stage of modelling the coefficient of heat transfer from the workpiece to the tool was set equal to 5 $W/m^2\cdot°C$, ambient temperature was 20°C, the temperature of instrument was 200°C. The speed of movement of the deforming tool was set equal to 10 mm s^{-1}, the coefficient of friction according to the law of Zibel was taken equal to 0,35.

Fig. 2 shows various fields of temperature distribution in the annular workpiece and the forming of the workpiece during rolling on a flat cylindrical mandrel. It is seen that the main deformation during rolling is concentrated on the outer surface of the workpiece due to low resistance of deformation of metal blanks in this field.

Considering the process of billet upsetting, it is shown that with increasing of die width, the workpiece width is also growing, and the widening of the workpiece is sufficiently intense.

The inner part of the ring is almost not widened, and the increase in the inner diameter of the ring is minimal.

The comparison of the pictures of deformation of the workpiece with different temperature fields shows that in the considered values of temperature distribution, its impact is minimal.

The maximal influence on the deformation has the size of the workpiece. In the case of expansion of the workpiece with a relatively thick wall the width change of the ring is more noticeable than for the billets with thin walls at an identical temperature field.

The graphs of the dependence of change of the size

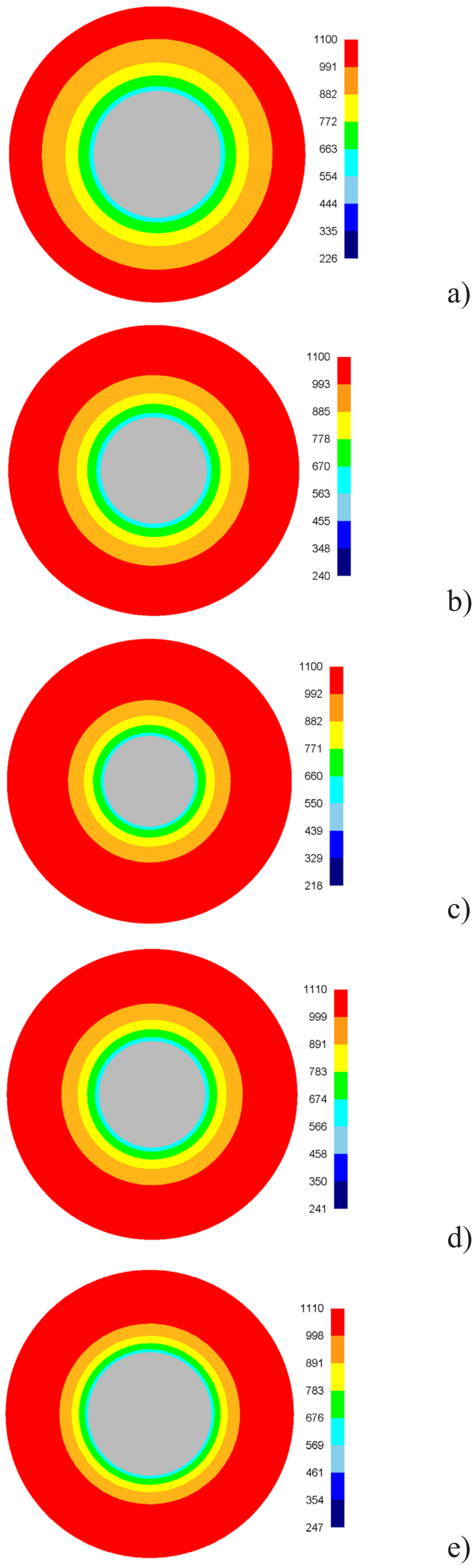

Fig. 2. Temperature fields of billets: (a) $S_0/h_0 = 1,0$ (Field 1); b) $S_0/h_0 = 1,3$ Field 1); c) $S_0/h_0 = 1,6$ (Field 1); d) $S_0/h_0 = 1,3$ (Field 2); e) $S_0/h_0 = 1,0$ (Field 2).

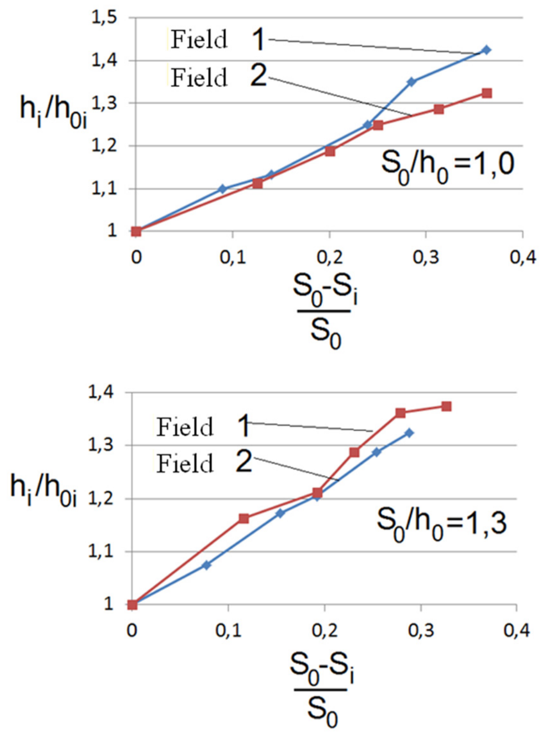

Fig. 3. The graphs of change of size of the workpiece, parameters of workpiece and parameters of temperature field.

of the workpiece, parameters of workpiece and parameters of temperature field were obtained (Fig. 3). It is seen that the broadening of the billet is directly proportional to the value of its compression. So for billet with $S_0/h_0 = 1.0$ when the compression increases from 0.1 to 0.36 relative width of a ring on the periphery is increased from 1.1 to 1.3. The influence of temperature field on deformation is observable only at sufficiently high compressions, equal to 0.2 or more.

Fig. 2 shows that the maximal difference of the width will be in workpiece with the maximal wall thickness (S_0/h_0=1,6). It reaches a value of 1.5 during a compression of 30 %.

The simulation of the workpiece expansion across its diameter was performed. The field strain distribution at various stages of expansion is illustrated in Fig. 4, which shows that the main deformation is concentrated in the peripheral layers of the workpiece at various stages of deformation. The simulation confirms the assumption about the nature of the deformation of the workpiece and the possibility of obtaining profiled rings with the use of traditional forging tools under the control of the temperature field of the workpiece.

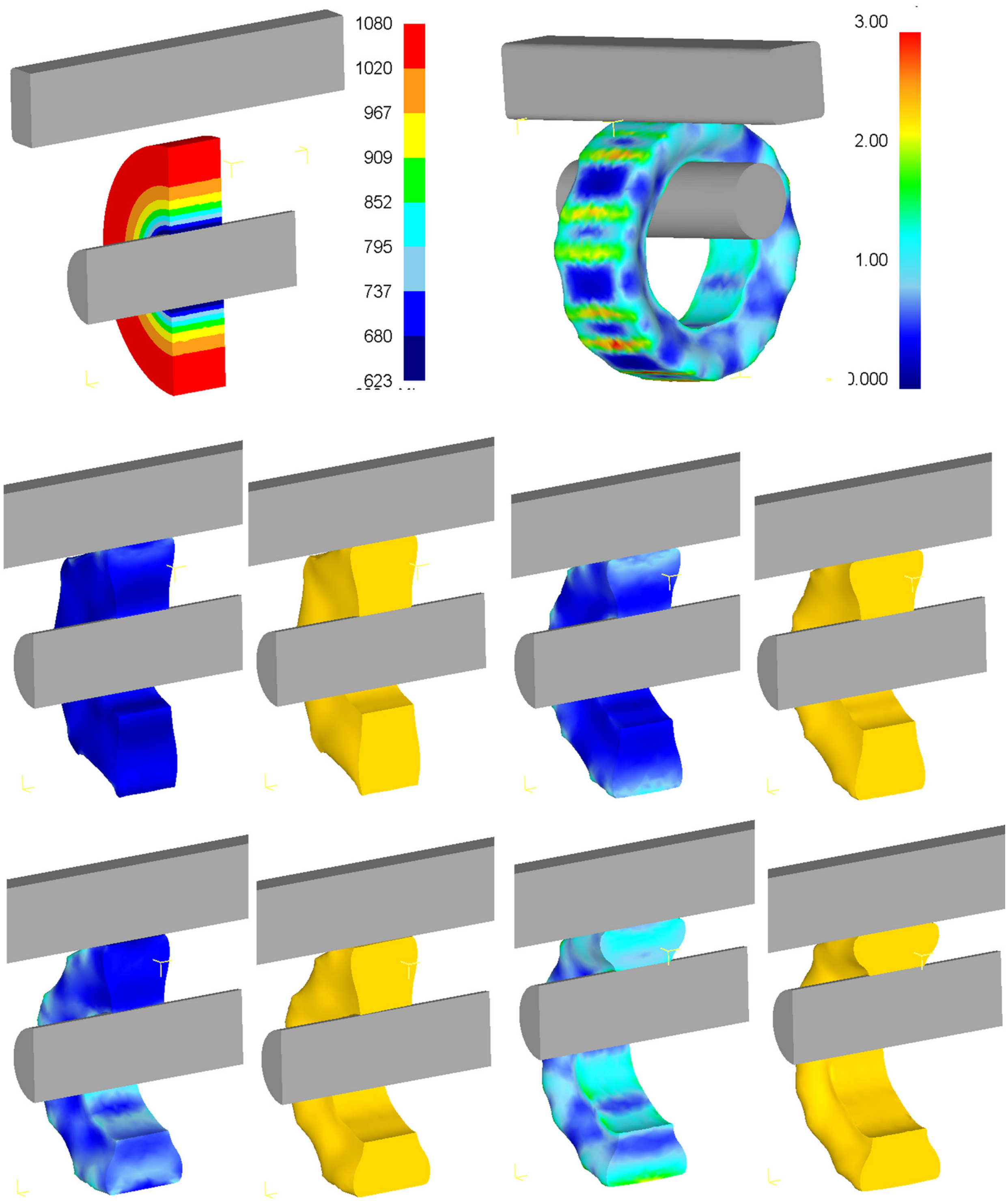

Fig. 4. The forming of the workpiece with inhomogeneous temperature field in the process of expansion on a mandrel.

Broaching the workpiece in cut dies

Common variant of the design of the dies with the angle of the neck 120 degrees was considered. The diameter of the billet was assumed to be 1000 mm. In the forging process different relative feeding of the workpiece from 0.3 to 0.9 was provided.

The compression was from 0.05 to 0.3 of the diameter of the workpiece. Considering inhomogeneous field

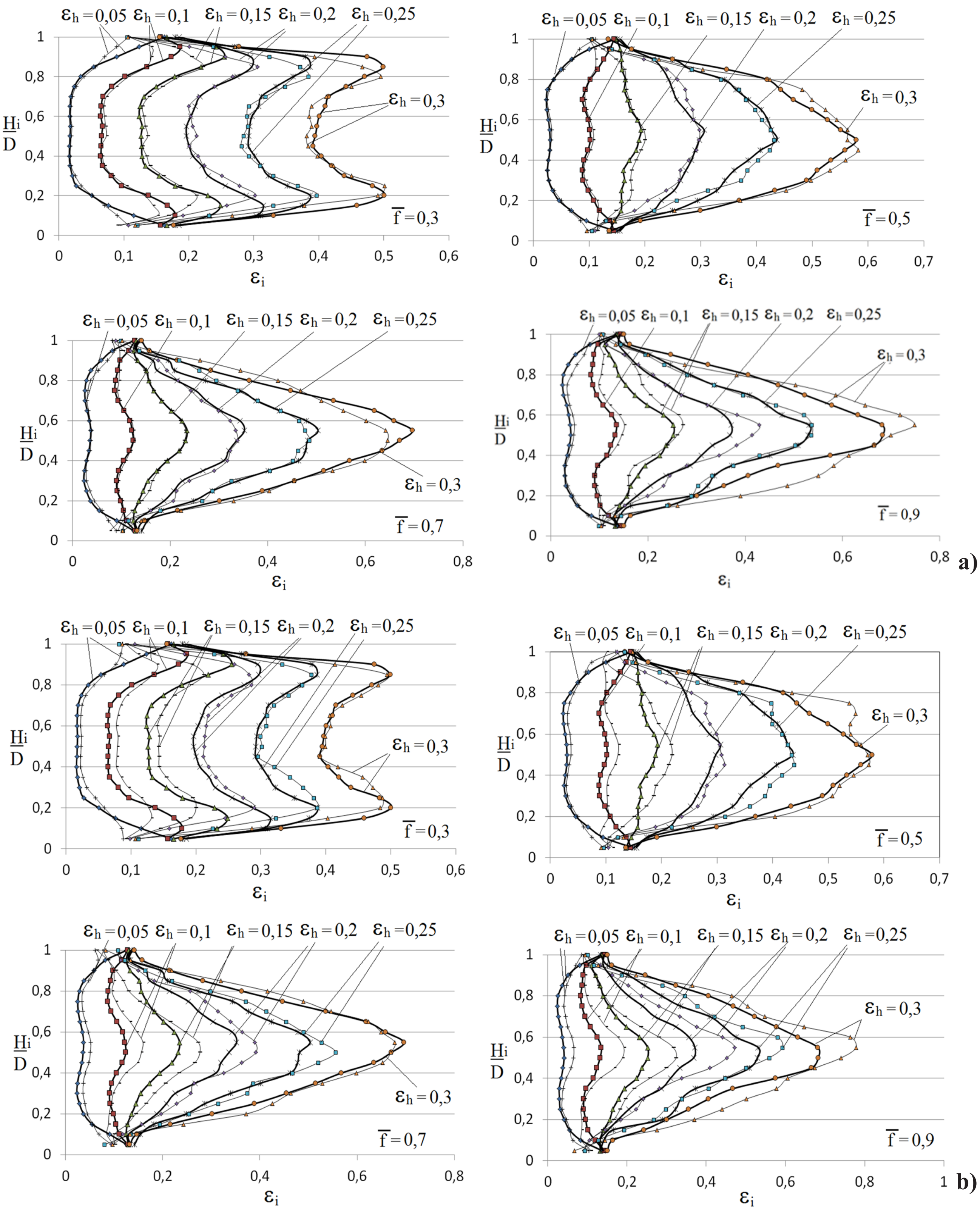

Fig. 5. Graphs of distribution of logarithmic strain intensity in the cross section of the workpiece at compression by cut dies with angle 120° (a - surface temperature of the workpiece 1000°C, b - surface temperature of the workpiece 800°C).

of temperature distribution in the volume of billet, field temperature of the surface of the workpiece was 1000°C and 800°C. The simulation determines the stress-strain state of the workpiece. The graphs of the strain distribution in the cross section of the billet during compression were obtained (Fig. 5).

The analysis of the data allows to conclude that in the case of broaching of the workpiece relative supply equal to 0.3 highest deformation concentrated at the surface of the workpiece at different compressions. The central part of the billet remains little researched. With the increase in compression from 0.1 to 0.3, the area of large deformations in the workpiece is displaced from the surface and is at a distance equal to 20 % of the diameter of the workpiece.

The relative increase in flow to 0.5 changes the distribution of deformations in the workpiece.

When compression is equal to 0.05 of the diameter of the workpiece it is observed an intensive development of surface layers of the workpiece, however, the difference of deformation between the central part and the workpiece surface is considerably less.

When the relative reductions equal from 0.1 to 0.15 of the diameter of the workpiece there is minimal heterogeneity of the strain distribution in the cross section of the workpiece. The increase in compression from 0.15 to 0.3 leads to a marked increase in the magnitude of intensity of deformation in the central part of the workpiece. In the process of broaching with relative feed rates of 0.7 and 0.9, the distribution of deformation does not change qualitatively, only an increase in intensity of deformation in the central part of the workpiece is observed. So when broaching of the workpiece with relative feed equal to 0.5, with relative compression equal to 0.3, the value of deformation intensity in the center of the workpiece is equal to 0.58, when broaching with a relative feed of 0.9 strain reaches a value of 0.68.

The influence of the temperature field on the strain

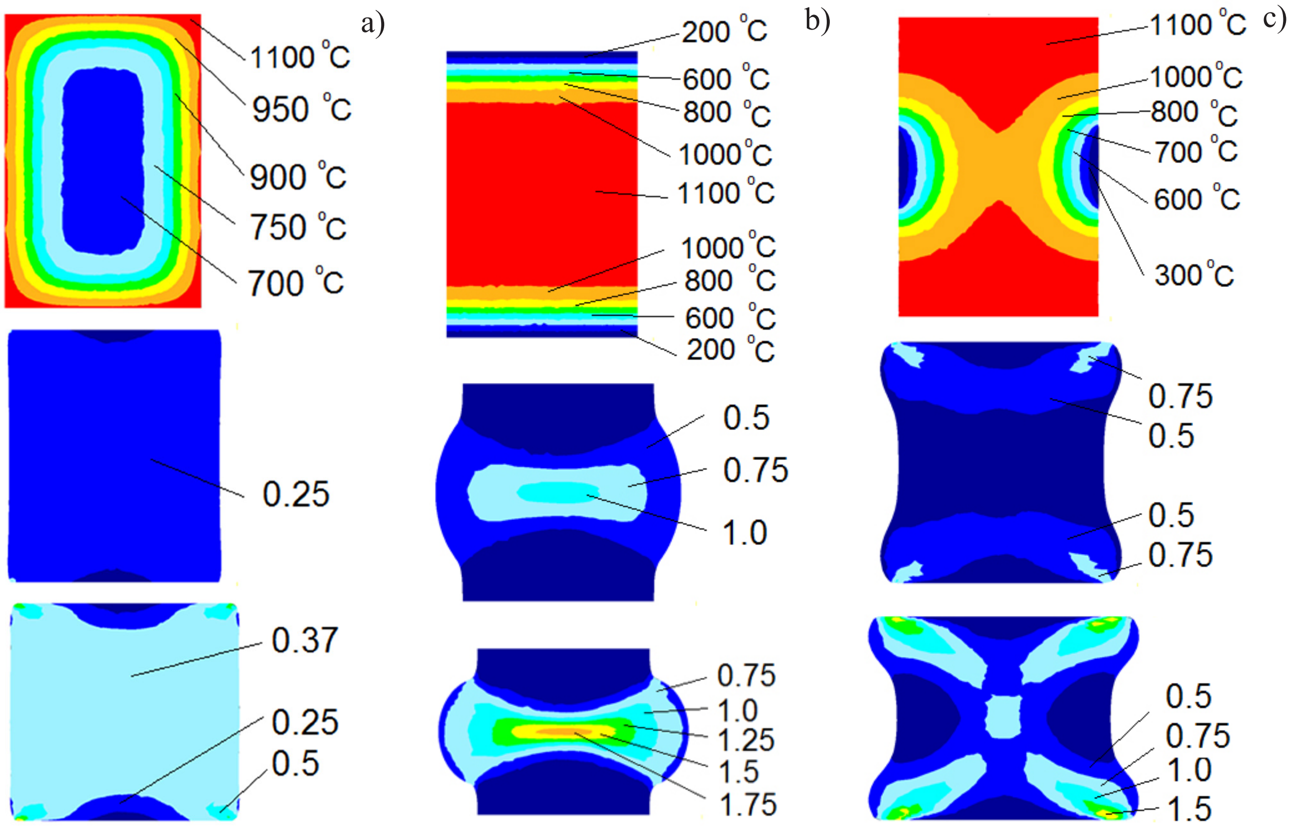

Fig. 6. The fields of distribution of temperature and intensity of deformation in longitudinal section of billets in the upsetting process at different schemes.

distribution in the cross section of the workpiece for the given scheme of deformation was considered. In Fig. 5a plots of the strain distribution for blanks with a surface temperature of 1000°C are shown (graphs are indicated by thin lines). It is established that for temperature difference between the surface of the workpiece and its core for the scheme of forging in cut dies, the difference in a deformed state in contrast to the uniform temperature distribution is small. There is a slight increase (within 5 %) in the deformations at the central layer of the workpiece.

Cooling the workpiece to a surface temperature of 800°C can change the distribution of deformations in the workpiece more significantly. From Fig. 5b, it is seen that deformation of the deep layers of the workpiece are increased by 15 - 20 %.

The analysis of the research allows to make next recommendations. To achieve a uniform strain distribution in the workpiece during the broaching in cut dies with the angle 120° it is recommended to hold the broaching with the relative feed rates more 0.5 and compression from 0.1 to 0.15 of the diameter of the workpiece. For the purpose of intensive study of the central layers of the billet, it is recommended to carry out the broaching with large relative feed rates more than 0.5 and large compressions more than 0.15 of the diameter of the workpiece.

Upsetting of discs

The simulation of upsetting process of the workpiece with diameter 1000 mm and height of 1500 mm with different temperature fields was performed. The workpiece material is steel 45. To ensure the necessary temperature field the simulation of different modes of heating and cooling is produced. The temperature field is shown in Fig. 5. The temperature of the deforming tool was set equal to 200°C, the coefficient of friction of plastic according to the law of Zibel - 0.35, the rate of deformation - 20 mm s^{-1}.

In result of simulation the fields of distribution of the logarithmic deformation intensity in the cross section of billet were received (Fig. 6). The analysis of the data allows to conclude about the correctness of the assumption of the nature of the deformation of the workpiece in the process of deformation of the flat plates.

In the case of upsetting of the workpiece with symmetric inhomogeneous temperature field (Fig. 6a) is shown that in the first stage of deformation on its side surface forms a concavity, which further aligns during precipitation, thus reducing the barreling. At a upsetting of 50 %, the barrel is completely missing.

In the case of upsetting of the workpiece with chilled ends (Fig. 6b) there is an intense deformation of the middle part of the workpiece, which allows to form disk-shaped with spikes. The metal blank having the ends of lower temperature, has a high resistance to deformation, which leads to priority deformation of the central part of the billet.

In the case of upsetting of workpiece with a cool middle part (Fig. 6c) the main deformation is concentrated at its end and in the process of upsetting we receive the workpiece with a shape resembling a coil.

Thus, it is shown that the control of the temperature fields allows to control deformation of the workpiece in forging processes of large billets.

CONCLUSIONS

Methods of details forging such as rings, discs and shafts from billet with non-uniform temperature field were proposed. The process of forging, which showed the effectiveness of a SSS control of the workpiece temperature field is studied. In the process of forging rings with the use of a smooth mandrel and a flat die is possible to obtain profiled rings only due to the inhomogeneous temperature field in the workpiece. In the process of forging of disks by upsetting, also using a flat die, it is possible to obtain forgings of complex shape.

REFERENCES

1. I.S. Aliev, Ya.G. Zhbankov, A.V. Perig, The factors influencing the parameters of forging of large forgings, Bulletin PNIPU. Engineering, materials science, 15, 1, 2013, 27-45, (in Russian).
2. V.N. Trubin, V.A. Shelehov, Forging of large billets. part 2, M.,,Metallurgy, 1965, (in Russian).
3. I.G. Zhbankov, A.V. Perig, L.I. Aliieva, New schemes of forging plates, shafts, and discs, Int. J. Adv. Manuf. Tech., 82, 2016, 1-4, 287-301.
4. I.G. Zhbankov, O.E. Markov, A.V. Perig, Rational Parameters of Profiled Workpieces for Upsetting Process, Int. J. Adv. Manuf. Tech., 71, 2014, 5-8, 808-810.
5. V.A. Tyurin, A.V. Hrabrov, V.N. Dubkov, L.P. Belova, Technological features of billets forging with inhomogeneous temperature field, Izvestiya Vuzov, Ferrous metallurgy, 9, 1980, 96-99, (in Russian).

6. G.A. Pimenov, Study of the conditions of forging of large forgings of steel 60HN, Ph.D. thesis, 1968, (in Russian).
7. A.S. 368924 USSR. Method of forging blanks type discs with hub. I.O. Katkov, V.M. Manaev, V.D. Soshin, № 1623459/25-27, (in Russian).
8. Ya.G. Zhbankov, A.A. Shvetc, M.A. Turchanin, Investigation of the stress state of the workpiece when broaching with inhomogeneous temperature field combined dies, Bulletin DSEA, 2, 31, 2013, 21-25, (in Russian).
9. V.K. Zablockiy, Ya.G. Zhbankov, A.A. Shvetc, Investigation of the strain state of the workpiece when drawing with inhomogeneous temperature field combined dies, Metal Forming, 4, 37, 2013, 70-73, (in Russian).