Evaluation of the manufacturability of aluminum alloy 1580 for sheet stamping by computer modeling

I. L. Konstantinov, *Candidate of Technical Sciences, Associate Professor of Metal Forming Department[1], e-mail: ilcon@mail.ru*
S. B. Sidelnikov, *Doctor of Technical Sciences, Professor of Metal Forming Department[1], e-mail: sbs270359@yandex.ru*
P. O. Yuryev, *Head of the Laboratory of Low-Carbon Metallurgy and Energy[1], e-mail: pashka_urew@mail.ru*
Yu. V. Baykovskiy, *Post-Graduate Student of Metal Forming Department[1], e-mail: baykovskjy98@gmail.com*

[1]Siberian Federal University, Krasnoyarsk, Russia.

The study of the manufacturability of industrial sheets made of aluminum alloy 1580 for the shape-changing operations of sheet stamping by computer modeling in the DEFORM program with subsequent verification by physical experiment was carried out. Drawing and flanging coefficients, at which it is possible to carry out these operations without cracking, have been established. The results of the research will expand the range of applications of this alloy and will make it possible to obtain parts with rigidity elements from it, which will increase the efficiency of their use. Configurations of such parts can be developed by computer modeling, the reliability of the results of which in this work is confirmed by physical experiments.
A study of the manufacturability of semi-finished sheet products made of aluminum alloy 1580 for sheet stamping was carried out. Industrial cold-rolled sheets with a thickness of 1 mm were used as the material. To evaluate the technological effectiveness, we chose such shape-changing operations of sheet stamping as drawing without thinning the wall of the "cup" part type and flanging of the blank in the form of a ring. The first stage was a computer simulation of these operations in the software package DEFORM, which allowed to determine the limiting values of drawing (K) and flanging (Co) coefficients, respectively 1.07 and 1.28, at which the values of the Cockroft-Latham criterion on the surface of virtual blanks did not reach a critical value equal to 1. Physical experiments have shown that drawing with a K coefficient greater than 1.07 leads to crack formation in the junction area of the part wall with its bottom. When flanging with a K_0 coefficient of more than 1.28, cracks occurred at the edge of the inner bore of the blank. It was also shown by computer simulation and then confirmed by physical experiment that the use of lubricant during drawing extends the deformability range of the alloy for this operation to a value of $K = 1.14$. The results of the research will allow to expand the range of application of this alloy and make it possible to produce parts with rigidity elements from it, which will increase the efficiency of their use. Configurations of such parts can be developed by computer modeling, the reliability of the results of which in this work is confirmed by physical experiments.

Key words: aluminum alloys, sheet stamping, scandium, sheet semi-manufactures, shape-changing operations, drawing, flanging, Cockroft-Latham criterion.

DOI: 10.17580/nfm.2023.01.09

Introduction

Currently, modeling is becoming a mandatory procedure for the development of new industrial production technologies, especially in energy- and material-intensive industries such as metallurgy, machine building, etc. Advances in digitalization have made computer simulation the most common and effective modeling tool. In metallurgy, the widest application and the most reliable results are given by modeling with the use of such programs as SolidCAST and PROCAST — in the foundry production, and SolidWork, ANSYS, DEFORM, QForm, Pam Stamp, etc. — in metal forming [1–5]. The use of computer modeling in the development of sheet metal forming technologies for new alloys is of great interest. For aluminum alloys, the following examples of the use of computer modeling for sheet metal forming can be cited. In [6] an analysis of the strain-hardening of an aluminum alloy designed for sheet metal forging is carried out. The authors of [7] described the effect of lubrication on technological efficiency in hot stamping of sheets of 6061 and 7075 aluminum alloys. In [8] during the study of the manufacturability of aluminum alloy 5182-O for the drawing operation using the Pam Stamp program, the size of the blank, the force of the holder of the blank and the depth of drawing were determined. In [9] studied the process of stamping aluminum alloy A6181-T4 in the manufacture of the hood of the car engine by simulation, and the results of simulation were tested and confirmed by stamping the hood of a production engine. The authors [10] applied a method combining theoretical analysis, computer modeling in the DYNAFORM program [11] and a physical experiment to reduce convexity, prevent the appearance of cracks and folds arising in the process of forging a double curvature part of 0.5 mm thick aluminum alloy 2A12. The optimal holder force, shape and size of the workpiece were determined by simulation. To confirm the virtual experiment, a tool (die) was made, physical modeling on which confirmed the results of computer modeling.

Table 1
Chemical composition of industrial sheets of 1580 alloy

Mass fraction of elements, %											
Fe	Si	Ti	Mn	Mg	Cr	Zr	Sc	Cu	Zn	Other	Al
0.20	0.08	0.02	0.58	4.9	0.15	0.11	0.10	0.04	0.15	0.12	rest

Table 2
Data for creating a model of the 1580 alloy for drawing operation modelling in DEFORM-3D

Parameter	Value
Die diameter, mm	28
Puncheon diameter, mm	25.5
Diameter of the blank D_1, mm	30
Diameter of the blank D_2, mm	32
Diameter of the blank D_3, mm	40
Thickness of the blank S, mm	1
Initial number of grid elements of the blank, pcs.	80000
Initial size of the blank grid element, mm	1.8
Calculated tool stroke in the first run, s/step	0.017
Number of calculation steps in the first run	600
Puncheon lowering speed, mm/s	1

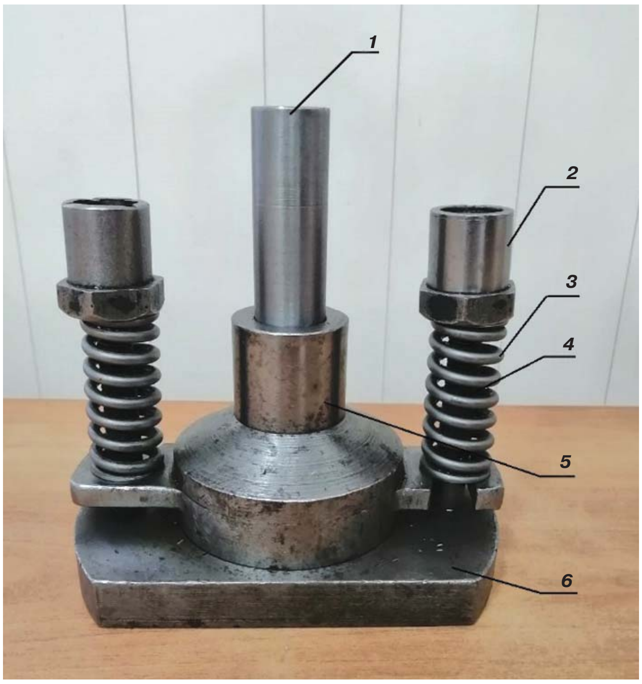

Fig. 1. Stamp (without top plate) for drawing without wall thinning and flanging:
1 — puncheon; *2* — faucet; *3* — spring; *4* — guide pillar; *5* — die; *6* — base

Great industrial interest, especially in the fields of aircraft and shipbuilding and rocket production, in new alloys of the aluminum-magnesium (magnalium) system with additives of rare-earth metals caused an urgent need to study their manufacturability. This is especially relevant to alloy 1580, which contains the expensive scandium additive. Among the industrial alloys, this alloy contains the minimum amount of scandium, ranging from 0.05 to 0.14% (wt.), which makes it the most attractive for the consumer. The structure of the alloy 1580, its manufacturability when casting and obtaining sheet semi-finished products in the laboratory and industrial conditions are well studied and described in the works [12—21]. The structure of Al – Mg – Sc alloys is described in [12—15], the manufacturability of alloy 1580 during casting is studied in [16], and the results of studies of its deformability in obtaining sheet semi-finished products in the laboratory and industrial conditions are given in the works [17—19]. Work [20] gives a review and discussion of developments in the field of hot forging of Al – Mg alloys, but manufacturability of new alloys of this system with scandium additives for cold sheet forging, given that the most popular sheet parts from them, studied little, which limits the introduction of these alloys in industry as a construction material. In addition, given the high cost of scandium-containing alloys, the development of technologies for producing parts from them by physical modeling methods alone should be considered a costly procedure.

Therefore, the aim of the work was to investigate the manufacturability of sheets of alloy 1580, manufactured in industrial conditions, for sheet stamping operations, by computer modeling. In order to achieve this goal, the following tasks were solved:

– computer modeling of shape-changing operations of sheet stamping of alloy 1580 sheets;

– study of manufacturability of 1580 alloy sheets for shape-changing sheet stamping operations by physical modeling method.

Materials and methods of research

The research was carried out in the laboratories of Siberian Federal University (SFU) on samples of industrial sheets of alloy 1580 with a thickness of 1.0 mm produced by the Russian metallurgical enterprise. The chemical composition of the sheets is shown in **Table 1.**

Technological capability of sheets for shape-changing operations of sheet stamping was carried out by drawing without wall thinning and flanging tests. The first test was performed by producing a hollow cup-type circular part from 30, 32, and 40 mm diameter blanks cut from a sheet. The second test was performed by flanging holes 18, 19 and 20 mm in diameer, cut in blanks with an outside diameter of 59 mm. For both tests, a Mario Di Maio hydraulic press with a force of 10 kN was used, and the die shown in **Fig. 1** was used as a tool.

Modeling was performed in the DEFORM-3D software package. The procedure for drawing simulation was as follows. At the first stage, using the built-in subprogram “Geometric primitives”, modeling objects in the form of a simplified model of the working tool and a workpiece were created. Next, the initial data for the simulation were set, which are presented in **Table 2.**

Table 3
Boundary conditions for simulating the drawing of 1580 alloy blanks

Parameter	Characteristic
Tool material	Rigid
Tool stroke	1/3 of the minimum size of the grid element
Starting temperature	Puncheon, blank: 20 °C
	Simulation without heat exchange
Friction conditions	Friction coefficient by Siebel:
	Blank-puncheon: 0.4
Symmetry condition	Tool – without symmetry
	Blank – without symmetry

Table 4
Data for creating the flanging model of the 1580 alloy blank in DEFORM-3D

Parameter	Value
Die diameter, mm	28
Puncheon diameter, mm	25.5
Diameter of the blank D, mm	59
Diameter of bore d_1, mm	18
Diameter of bore d_2, mm	19
Diameter of bore d_3, mm	20
Thickness of the blank S, mm	1
Initial number of grid elements of the blank, pcs.	60000
Initial size of the blank grid element, mm	1.2
Calculated tool stroke in the first run, s/step	0.022
Number of calculation steps in the first run	500
Puncheon lowering speed, mm/s	1

At the next stage, the parameters of the relative positions of the models were specified, including the area of their contact, and after positioning the objects, the boundary conditions were introduced (**Table 3**).

Rheological properties of alloy 1580 were entered into DEFORM program in the manual mode according to the data of [21] and the results of tests in the laboratory conditions of the Department of Metal Forming of SFU. The remaining data (Young's modulus, Poisson's ratio) were taken from the DEFORM database, as for the A-5083 alloy, which is the closest analogue of the 1580 alloy.

After all the simulation conditions were set, a database was generated for each blank to start the calculation, which was loaded into the processor module. After calculation, the database models, supplemented by the results of calculations, were loaded into the DEFORM-3D postprocessor, where a comprehensive analysis of the process by a number of key characteristics, including the visualization of the simulation object and display of the parameters of the stress-strain state of the blanks at each step of the models.

The modeling of the flanging process was carried out similarly to the modeling of the drawing process. The output data for modeling the flanging process are presented in **Table 4**.

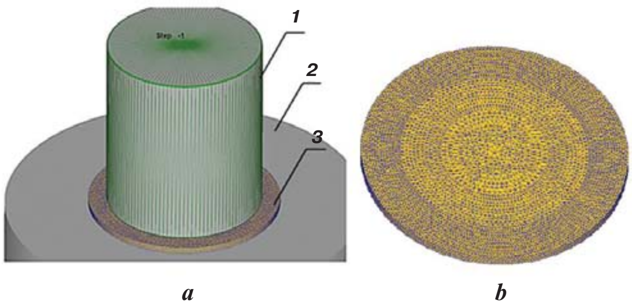

Fig. 2. A computer model of the die (*a*) and blank for drawing operation with the finite element grid (*b*):
1 — puncheon; *2* — die; *3* — blank

The boundary conditions in the simulation of the flanging process were identical to those used in the drawing simulation **(Table 2)**.

Results and discussion

A computer model of the die and blank for drawing operation with the finite element grid are shown on **Fig. 2**.

The Cockcroft-Latham fracture criterion calculation subprogram was used to simulate drawing and flanging ($C_{C\text{-}L}$), which makes it possible to predict the occurrence of cracks in dangerous areas of the drawn component, in this case in the junction of the "cup" part walls into its bottom. According to the Cockcroft-Latham fracture model, the condition of integrity preservation of a material point is checked by the following inequality:

$$\int_0^{\varepsilon_i} \frac{\sigma_1}{\sigma_i} d\varepsilon_i < c_{lim},$$

where σ_1 – the main positive normal tension; ε_i – strain intensity; σ_i – stress intensity; c_{lim} – the limit value of the Cockcroft-Latham index, corresponding to the moment of metal destruction. The left part of inequality (c) characterizes the specific work of elementary tensile forces. Thus, the destruction of metal according to this model occurs when the following condition is met:

$$c = c_{lim}$$

In this work, in accordance with the sources [22, 23], it was assumed that the Cockcroft-Latham criterion ($C_{C\text{-}L}$) should not reach 1, and then the destruction of the workpiece during drawing should not occur.

The manufacturability of shape change by drawing is usually evaluated by the drawing coefficient K, which shows the possibility of obtaining a hollow part from a flat blanks during the transition without destroying it. [24]. This indicator is calculated as the quotient of the diameter of the blank D divided by the diameter of the part d. In the experiment, the diameter of the drawing die forming the outer diameter of the part was 28 mm, so the work investigated the possibility of obtaining a hollow part at three values of K, respectively 1.07, 1.14 and 1.43.

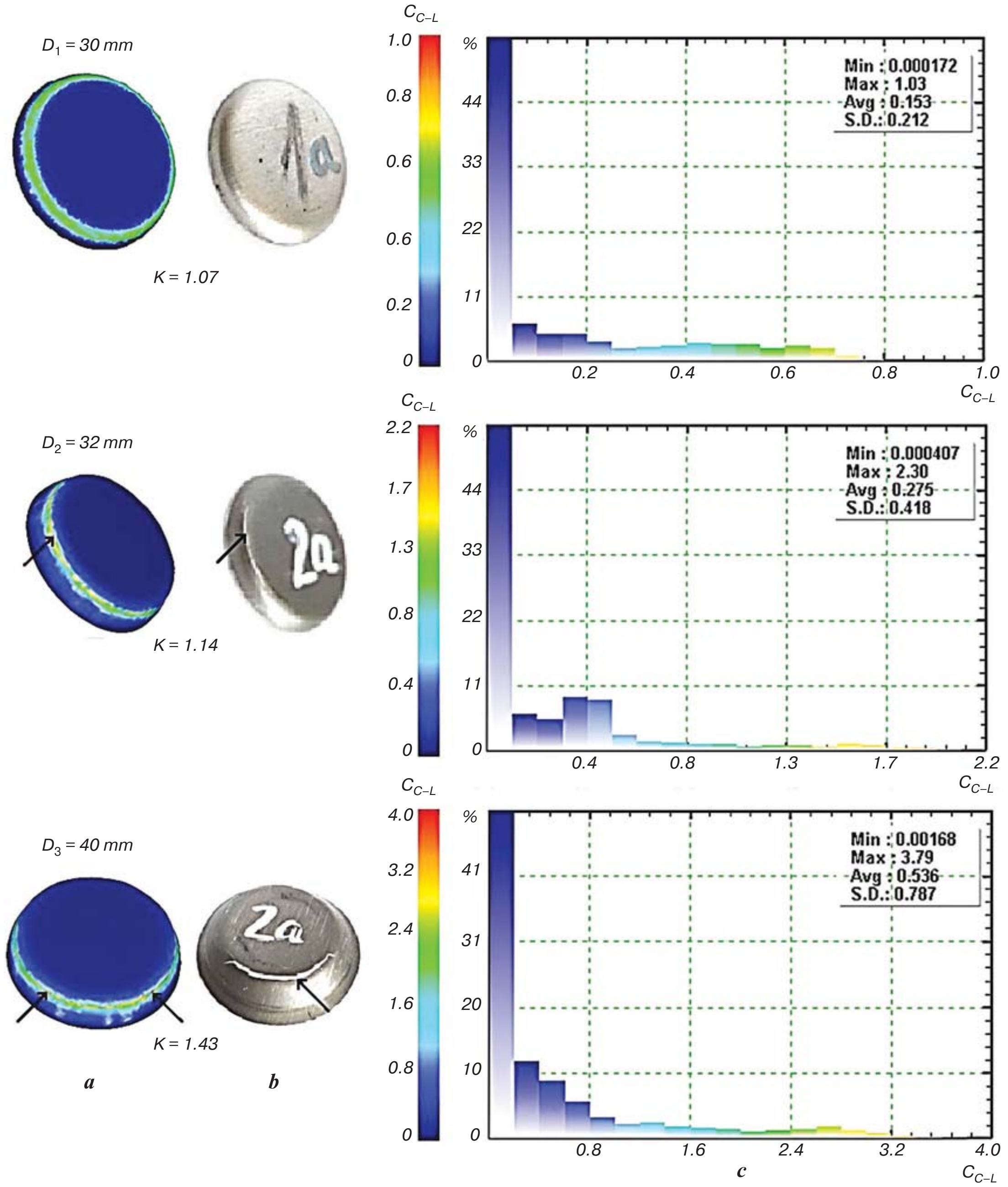

Fig. 3. Results of computer and physical simulation of drawing without wall thinning:
a – computer model; *b* – physical model; *c* – Cockcroft-Latham fracture criterion distribution histogram

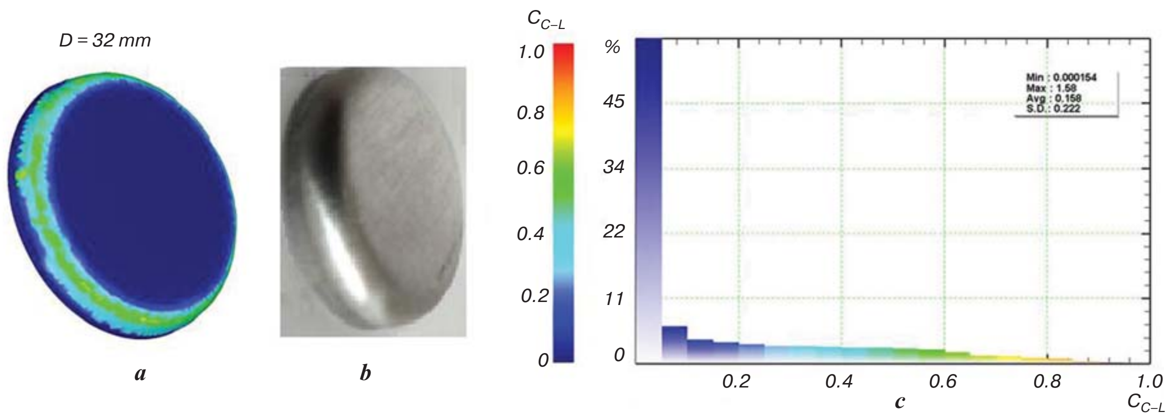

Fig. 4. Results of computer and physical simulation of the drawing with lubricant:
a – computer model; *b* – physical model; *c* – Cockcroft-Latham fracture criterion distribution histogram

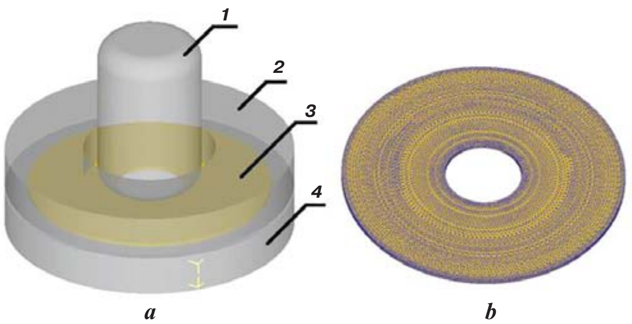

Fig. 5. Computer model of the die (*a*) and the flanging blank with finite element grid (*b*):
1 – puncheon; *2* – upper plate; *3* – blank; *4* – die

Simulation results showed that at $K = 1.07$ the $C_{C\text{-}L}$ criterion values did not reach 1. At $K = 1.14$ there appeared areas in places of junction of the part wall into its bottom with values $C_{C\text{-}L}$ exceeding 1, and at $K = 1.43$ the share of such areas significantly increased.

Verification by physical experiment, showed that in the first case, the operation of drawing the part passed without cracks, in the second case, at the transition section of the part wall to its bottom, crack formation occurred, and at $K = 1.43$ already observed crack opening. The results of the virtual and physical experiment are shown in **Fig. 3**. The arrows on the virtual model indicate areas of the blank in which the values of the Cockcroft-Latham criterion are close to 1, and on the physical model they show the locations of cracks.

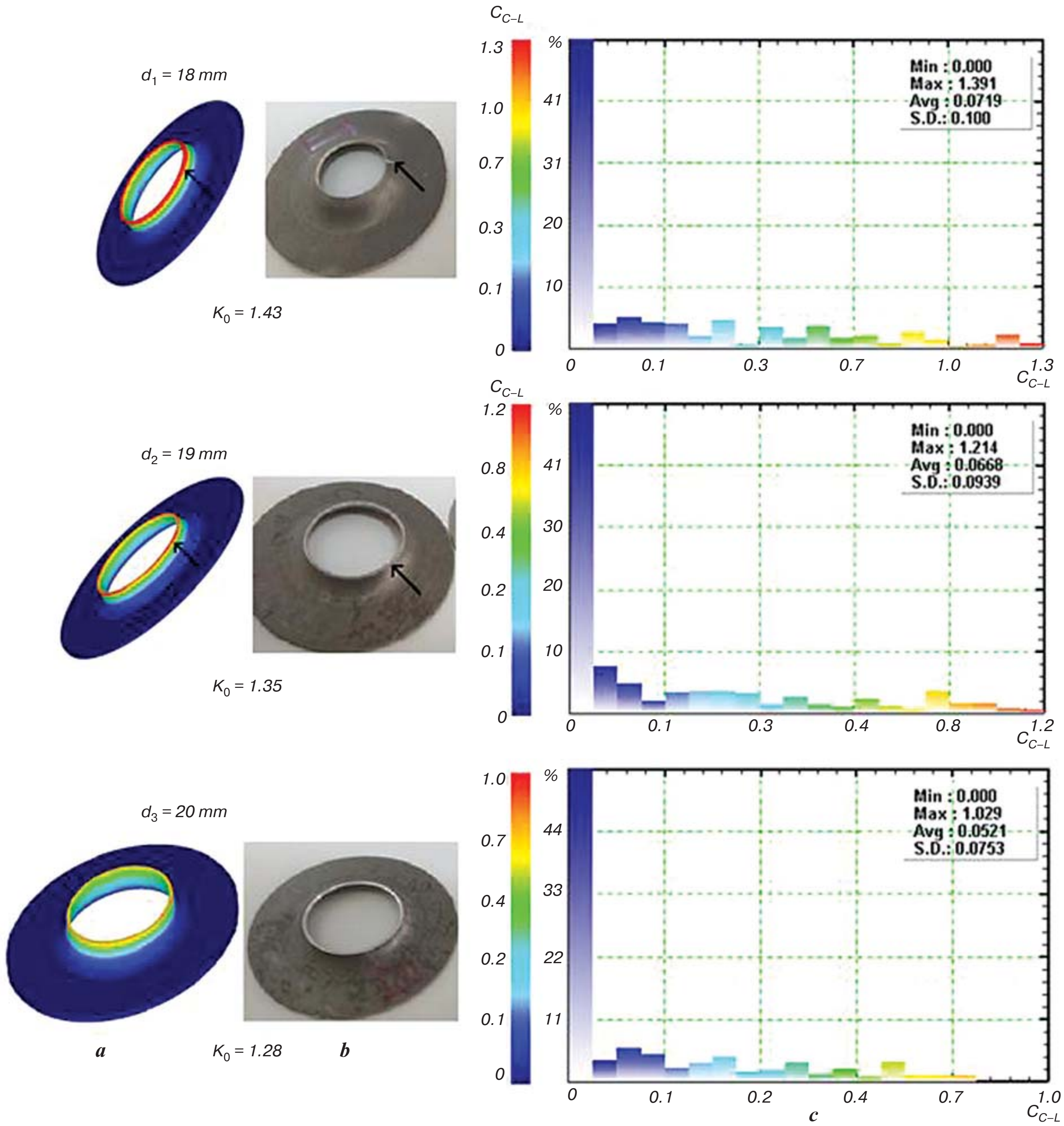

Fig. 6. Results of computer and physical modeling of the flanging:
a — computer model; *b* — physical model; *c* — Cockcroft-Latham fracture criterion distribution histogram

To investigate the possibility of increasing the technological ductility of the 1580 alloy and, therefore, obtaining deeper parts when drawing in a virtual and then in a physical experiment, lubrication was applied, which allowed to form a part "cup" without fracture at $K = 1.14$ (**Fig. 4**). In addition, it can also be recommended to carry out the process of drawing in several steps, and provide heat treatment between steps to restore plasticity.

Fig. 5 shows a computer model of the working tool and blank with a finite element grid for the flanging test.

The main indicator of the shape change of the sheet blank when flanging is the flanging coefficient K_o, which characterizes the ability to obtain the maximum flange height around the hole, previously made in the blank. This indicator is equal to the ratio of the diameter of the hole before flanging d_o to the diameter of the hole after flanging d_1, measured along the midline.

Simulation results **(Fig. 6)** showed that with $K_o = 1.43$ on the model at the edges of the formed side, were found areas with the values of the criterion $C_{C\text{-}L}$ significantly higher than 1. At $K_o = 1.35$ the share of such sites decreased significantly, and at $K_o = 1.28$ there were no such sites.

The physical experiment, showed that in the first case, the flanging of the part passed with the formation of a crack on the edge of the flange, in the second case, the area with the beginning of crack formation on the edge of the flange was found, and at $K_o = 1.28$ no formation of cracks was observed.

Also, as in the case of drawing, the arrows on the virtual model indicate areas of the blank in which the values of the Cockcroft-Latham criterion are close to 1, and on the physical model they show the locations of cracks.

Conclusion

At present, aluminum alloy 1580 is mainly used or planned to be used as welded sheet parts for hull cladding in aircraft, shipbuilding, and rocket production, as well as in the manufacture of storage tanks for various purposes. For such parts usually only separating operations of sheet stamping are used, such as cutting, punching, piercing, etc., and of the shape-changing ones - bending. The results obtained by computer modeling and then verified by physical experiment quantitatively characterize the manufacturability of the alloy for such forming operations of sheet stamping as drawing and flanging. This knowledge will expand the range of applications for the 1580 alloy and make it possible to produce parts with elements such as stiffeners, ribs, flanges, etc., which will increase the alloy's efficiency. At the same time, the configurations of such parts can be developed by computer simulation, the validity of the results of which in this work is confirmed by physical experiments.

Acknowledgments

The work was performed by the Laboratory of Low-Carbon Metallurgy and Energy under the state assignment of the FSAEI HE "Siberian Federal University", a participating organization of the REC "Yenisei Siberia", as part of the national project "Science and Universities", project number FSRZ-2021-0010.

References

1. Nikanorov A. V. Comparative Analysis of Computer Programs for Foundry Process Simulation. *Proceedings of Irkutsk State Technical University*. 2018. Vol. 22, Iss. 11. pp. 209–218.

2. ProCAST Official Website. URL: https://www.esi-group.com/products/casting (Accessed: 11.04.23).

3. DEFORM Official Website. URL: https://www.deform.com (Accessed: 11.04.23).

4. QFORM Offical Website. URL: https://qform3d.ru (Accessed: 11.04.23).

5. Semenov E. I. Application of the PAM-STAMP Software Package for Automating the Sheet Stamping Processes Design. *Mechanical Engineering and Engineering Education*. 2008. Iss. 3. pp. 42–47.

6. Golovashchenko S., Zdravkovic S., Reinber N., Nasheralahkami S., Zhou W. Analysis of Material Work Hardening and Fracture Strains for Sheet Metal Stamping Processes. *Forming the Future: Proceedings of the 13th International Conference on the Technology of Plasticity*. Springer, 2021. pp. 2777–2788.

7. Liu Yong, Zhoujie Zhu, Zijian Wang, Bin Zhu, Yilin Wang, Zhang Yishe Formability and Lubrication of a B-pillar in Hot Stamping with 6061 and 7075 Aluminum Alloy Sheets. *Procedia Engineering*. 2017. Vol. 207. pp. 723–728.

8. Ahmetoglu M. A., Kinzel G., Altan T. Forming of Aluminum Alloys—Application of Computer Simulations and Blank Holding Force Control. *Journal of Materials Processing Technology*. 1997. Vol. 71, Iss. 1. pp. 147–151.

9. Lin, C.-W., Chen, F.-K. Formability Study on Stamping an Engine Hood with Aluminum Alloy Sheet. *IOP Conference Series: Materials Science and Engineering*. 2019. Vol. 651, Iss. 1. 012103.

10. Zhang De-Hai, Bai Dai-Ping, Liu Ji-Bin, Guo Zhe, Guo Zhe, Guo Cheng. Formability behaviors of 2A12 thin-wall part based on DYNAFORM and stamping experiment. *Composites Part B: Engineering*. 2013. Vol. 55. pp. 591–598.

11. Dynaform Official Website. URL: https://www.eta.com/products/dynaform/ (Accessed: 11.04.23).

12. Konstantinov I. L., Yuryev P. O., Baranov V. N., Bezrukikh A. I., Sidelnikov S. B., Orelkina T. A., Voroshilova M. V., Murashkin M. Y., Baykovskiy Yu. V., Partyko E. G., Stepanenko N. A., Mansurov Y. M. Study the Influence of Scandium Content and Annealing Regimes on the Properties of Alloys 1580 and 1581. *International Journal of Lightweight Materials and Manufacture*. 2023. Vol. 6, Iss. 1. pp. 15–24.

13. Pereiraa P. H. R., Wang Y. C., Huang Y., Langdon T. G. Influence of Grain Size on the Flow Properties of an Al – Mg –

Sc Alloy Over Seven Orders of Magnitude of Strain Rate. *Materials Science & Engineering: A*. 2017. Vol. 685. pp. 367–376.

14. Buranova Yu., Kulitskiy V., Peterlechner M., Mogucheva A., Kaibyshev R., Divinski S. V., Wilde G. $Al_3(Sc,Zr)$-Based Precipitates in Al – Mg Alloy: Effect of Severe Deformation. *Acta Materialia*. 2017. Vol. 124. pp. 210–224.

15. Zakharov V. V., Filatov Y. A., Fisenko I. A. Scandium Alloying of Aluminum Alloys. *Metal Science and Heat Treatment*. 2020. Vol. 62, Iss. 7-8. pp. 518–523.

16. Wang R., Jiang S., Chen B., Zhu Z. Size Effect in the Al3Sc Dispersoid-Mediated Precipitation and Mechanical/Electrical Properties of Al – Mg – Si – Sc Alloys. *Journal of Materials Science & Technology*. 2020. Vol. 57. pp. 78–84.

17. Mann V. Kh., Sidelnikov S. B., Konstantinov I. L., Baranov V. N., Dovzhenko I. N., Voroshilov D. S., Lopatina E. S., Yakivyuk O. V., Belokonova I. N. Modeling and Investigation of the Process of Hot Rolling of Large-Sized Ingots From Aluminum Alloy of the Al–Mg System, Economically Alloyed by Scandium. *Materials Science Forum*. 2019. Vol. 943. pp 58–65.

18. Yashin V. V., Aryshenskiy V. Yu., Latushkin I. A., Tepterev V. S. Substantiation of a Manufacturing Technology of Flat Rolled Products from Al – Mg – Sc Based Alloys for the Aerospace Industry. *Tsvetnye Metally*. 2018. No. 7. pp. 75–82.

19. Konstantinov I. L., Baranov V. N., Sidelnikov S. B., Arnautov A. D., Voroshilov D. S., Dovzhenko N. N., Zenkin E. Yu., Bezrukikh A. I., Dovzhenko I. N., Yuryev P. O. Investigation of Cold Rolling Modes of 1580 Alloy by the Method of Computer Simulation. *The International Journal of Advanced Manufacturing Technology*. 2021. Vol. 112, Iss. 1-2. pp. 1965– 1972.

20. Toros S., Ozturk F., Kacar I. Review of Warm Forming of Aluminum–Magnesium Alloys. *Journal of Materials Processing Technology*. 2008. Vol. 207, Iss. 1-3. pp. 1–12.

21. Dovzhenko N. N., Rushchits S. V., Dovzhenko I. N., Yurev P. O. Understanding the Behaviour of Aluminium Alloy P-1580 Sparingly Doped with Scandium Under Hot Deformation. *Tsvetnye Metally*. 2019. No. 9. pp. 80–86.

22. Cockcroft M. G., Latham D. J. Ductility and the Workability of Metals. *Journal of the Institute of Metals*. 1968. Vol. 96. pp. 33–39.

23. Botkin A. V., Valiev R. Z., Stepin P. S., Baimukhametov A. Kh. Evaluating the Metal Damage During Cold Plastic Deformation Using the Cockroft-Latham Fracture Model. *Deformatsiya i Razrushenie Materialov*. 2011. Iss. 7. pp. 17–22.

24. Forging and Stamping: Reference: in 4 Vols. Vol. 4 Sheet Stamping. Ed. by A. D. Matveev. Moscow: Mechanical Engineering, 1987. 544 p.

NFM