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Xiang ZHANG[1], Volodymyr BORYSEVYCH[1], Jingming CHEN[2]

[1] ***National Aerospace University "Kharkiv Aviation Institute", Ukraine***
[2] ***Northwestern Polytechnical University Ming de College, China***

SELECTION OF THE RATIONAL GEOMETRY OF SPECIMEN FOR COMPRESSION TEST

The object of study in this article is the conditions during the compression test. The subject matter is the models that simulate the physical processes during the compression test. The goal is to obtain models, which allow obtaining real information about stress-strain dependence during compression. The tasks to solve are to develop a three-dimensional computer model of a specimen subjected to compression that geometry allows to avoid the nonuniform distribution of stress-strain state. The upsetting of cylindrical specimens is one of the most commonly used methods for compression tests. However, due to the frictional force on both ends of the specimen, a barreling shape is likely to appear in the middle of the cylinder during the compression process, resulting in inaccurate mechanical properties of the final measured specimens. Therefore, this paper conducts qualitative and quantitative research on the physical parameters that affect the degree of barreling during the upsetting process of cylindrical specimens. The following results were obtained. The Concave End Face (CEF)-Upsetting and Headed Specimen (HS)-Upsetting methods have a significant effect on reducing the barreling degree. The smallest difference in the barreling degree is almost close to 101.8 % that appears in the CEF-Upsetting. Further analysis shows that the above two methods have similar principles for reducing the barreling degree, and both reduce the barreling degree in the middle by increasing the deformation of the workpiece ends. Then, the influence of the deformation of the workpiece head zone on the deformation of the non-end (gauge length) zone is analyzed. The rounded corners of the transition zone between the workpiece end zone and the non-end zones of HS-Upsetting have a great influence on the generation of forming defects. The end face groove size of CEF-Upsetting has a significant effect on the barreling degree after upsetting. Under the same other conditions, the barreling degree is the smallest when the ratio of the concave depth (a/D) is 0.12, when the ratio of the concave diameter(Dc/D) doesn't exceed 0.6, the smaller the ratio of the concave diameter(Dc/D), the smaller the barreling degree. Finally, through the design of the orthogonal test, the functional relationship between the barreling degree and the dimension parameters of the workpiece ends zone is established. Conclusions: It doesn't prove the feasibility of barreling-less upsetting only, but also provides theoretical support for actual production in the future.

Keywords: *upsetting; barreling degree; compression test; stress-strain state; computer model; simulation.*

Introduction

Upsetting is an important forming method in the forming process of large forgings. Due to the unavoidable friction between the end face of the workpiece and the flat anvil, the uneven deformation of the metal inside the workpiece is caused. In addition, the side surface of the workpiece will have obvious barreling after upsetting, which will inevitably cause the uneven grain size of the forgings and cause the uneven performance of the metal forging. Therefore, in order to ensure the quality of forgings, the barreling should be minimized and the uniformity of the deformation of the upsetting should be improved [1]. The traditional process plan of reducing the barreling is mainly achieved by reducing friction between the end face and the flat anvil. The main technological measures include:

1. The Concave End Face Upsetting (CEF).
2. The Groove End Face Upsetting (GEF).
3. the Metal Pad Upsetting.
4. The Headed Specimen (HS) Upsetting.
5. The Cylinder Upsetting.

A large number of scholars have done qualitative physical and numerical simulations. Liu [2] conducted physical simulation experiments on the upsetting of the Concave End Face, and calculated the relationship between the barreling size and the ratio of the reduction, the ratio of height to diameter. But, she did not consider the influence of the diameter ratio of the concave end face on the barreling shape. In fact, our experiments proved that the diameter ratio of the concave end face has a great influence on the barreling shape. Sun [3] et al. carried out numerical simulations on the traditional measures to reduce the upsetting barreling and found that compared with ordinary upsetting, the Side Recessed Workpiece Upsetting, the Soft Metal Pad Upsetting and the Ring Internal Upsetting can be different to different degrees, the minimum Relative diameter ratio is 0.2744. But, the

Ring Internal Upsetting is not suitable for compression test and It changes the stress state of the workpiece. Wang [4] used DEFORM finite element analysis software to simulate and compare general Cylinder Upsetting, the Ring Internal Upsetting, the Concave End Face Upsetting and the Tapered Plate Upsetting. It is found that the effect of the Concave End Face Upsetting to reduce the barreling is the most obvious, the minimum relative diameter ratio is 0.179. However, its relative diameter ratio is the ratio of the diameter of the barreling after upsetting to the diameter of the original workpiece, so it cannot accurately reflect the actual size of the barreling after upsetting. Therefore, in order to predict the formation of barreling shape, we must carry out quantitative analysis and research on the occurrence of upsetting barreling shape.

1. Finite Element models

The forging of large forgings is usually done on a hydraulic press and each pressing is instantaneous, so displacement loads are used to simulate the static pressure of the press. Ignoring the temperature change of the forging during one reduction process, it is assumed to be a constant temperature of 850°C [5]. Taking the cylinder with a height of 150 mm and a diameter of 100 mm, that is, the original height and diameter is 1.5. And the reduction ratio is 30%. The workpiece is divided into 3000 grid units, the friction coefficient between the workpiece and the flat anvil is 0.3, and the moving speed of the upper flat anvil is 20 mm/s. According to the symmetry of structure and load, 1/2 of the entire central symmetry plane can be used for modeling. The model is shown in Fig. 1.

2. Results and Analysis

2.1. Stress-Effective

Fig. 2 is the distribution of stress-effective diagram of the workpiece after simulation of 4 models. Due to the different end face structures of the workpieces, their stress distributions are different in 4 models. The maximum effective stress appears on the outer edge of the end face in the Cylinder-Upsetting and the CEF-UPsetting. While it appears at the upper edge of the groove in the GEF-Upsetting and the transition fillet in the HS-Upsetting. The stress concentration areas not only hinder the flow of metal but also increase the risk of defects. And the HS-Upsetting is the worst. The stress distribution of the rest except the end face is relatively uniform in all 4 models. Therefore, all 4 models can be used for compression tests if the impact of the end face stress is not considered.

2.2. Strain-Effective

Fig. 3 shows the distribution of strain-effective diagram of the workpiece after the simulation of 4 models of upsetting. Due to the friction of the end face, Dead zone appeared on the end face of the workpieces in all 4 models.

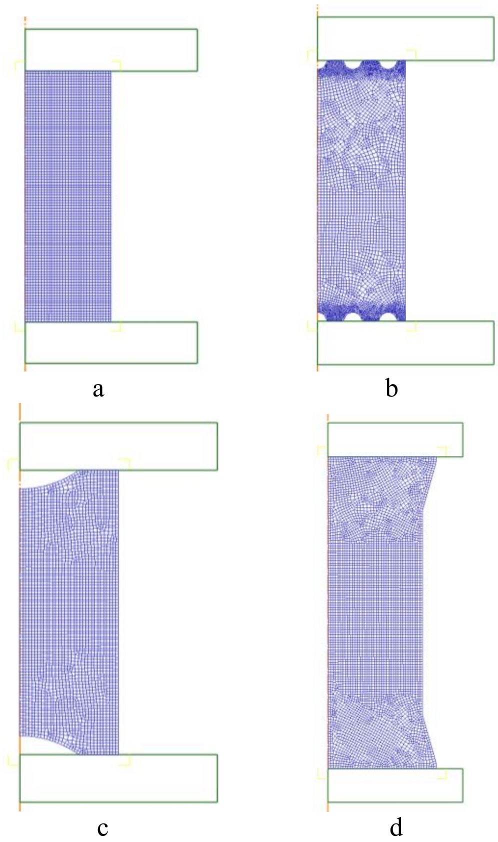

Fig. 1. The Finite Element Models of Deform-2D:
a – the Model of the Cylinder-Upseting,
b – the Model of the CEF-UPsetting,
c – the Model of the GEF-Upsetting,
d – the Model of the HS-Upsetting

The largest dead zone appears at the center of the end face of the Cylinder-Upsetting. Due to the recessed end face, the smallest dead zone appears at the center of the end face in the CEF-Upsetting. It reduces the area of the dead zone at the center of the end face in the GEF-Upsetting, but a gully dead zone appears between the each annular groove, which hinders the radial flow of the metal at the center of the end face, causing the groove near the center to fail to fully compress combine. And the most uneven deformation appears on the end face in GEF-Upsetting. Although a large dead zone appeared at the end face in the HS-Upsetting, there is no obvious dead zone in the gauge length part. Therefore, the CEF-Upsetting and the HS-Upsetting can be used for compression tests if the influence of the end face deformation is not considered.

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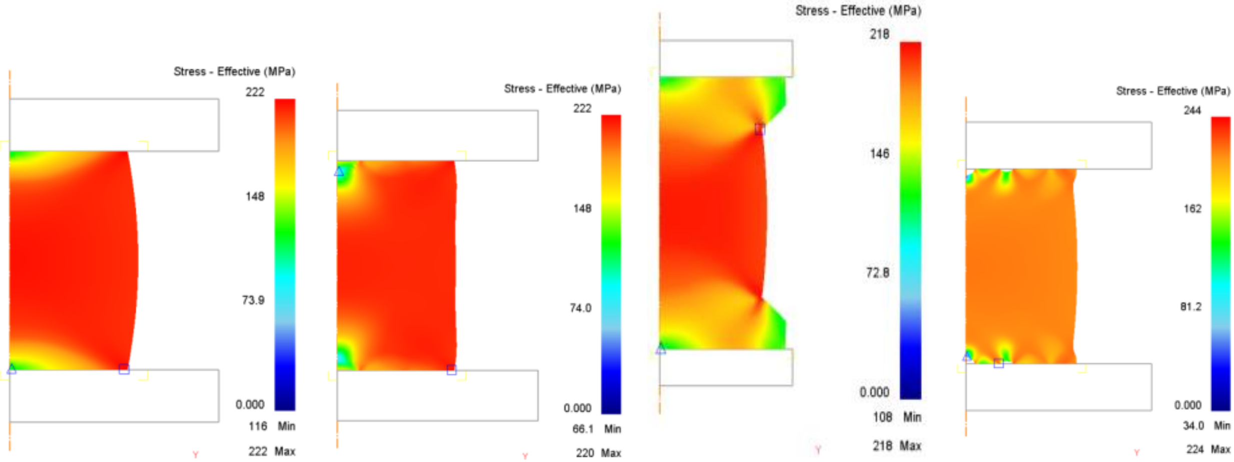
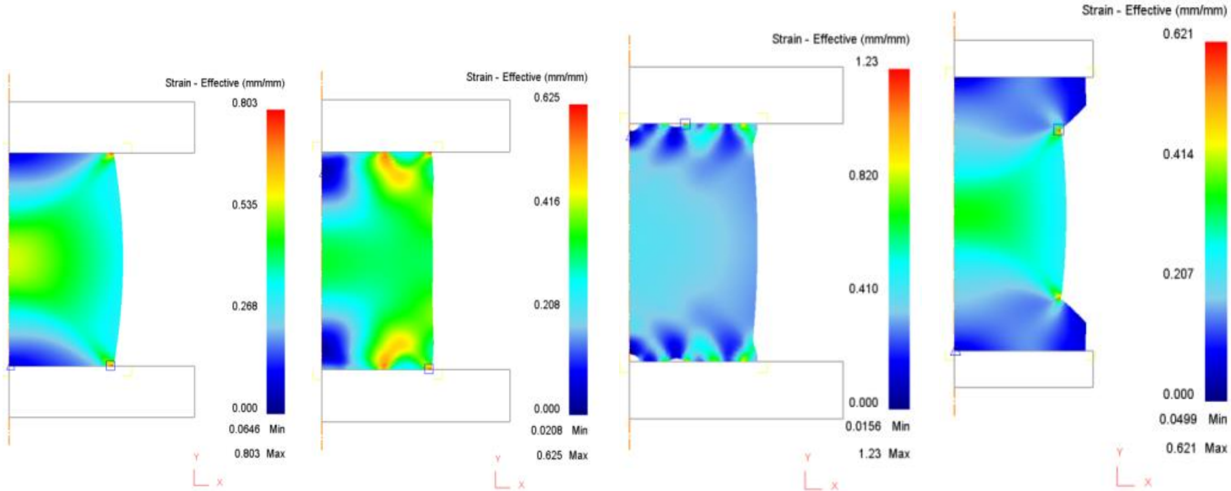


a b c d

Fig. 2. The Distribution of Stress-Effective Diagram: a – the Stress-Effective of Cylinder-Upseting, b – the Stress-Effective of CEF-Upsetting, c – the Stress-Effective of GEF-UPsetting, d – the Model of the HS-Upsetting

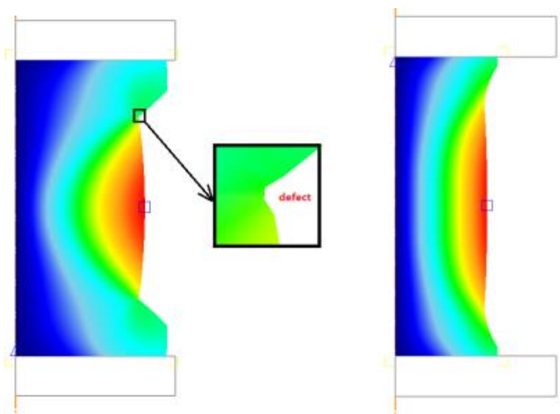


a b c d

Fig. 3. Strain-Effective Diagram: a – the Strain-Effective of Cylinder-Upseting, b – the Strain-Effective of CEF-Upsetting, c – the Strain-Effective of GEF-Upsetting, d – the Strain-Effective of the HS-Upsetting

2.3. End Face Deformation Analysis

In the HS-Upsetting uniform deformation occurs in the main deformation zone. The reason is their end faces are involved in the deformation so as to reduce the impact of end-face friction. However, it also brings other problems. As shown in Fig. 4, a, the transition area between the head and the gauge length appears a defect in the HS-Upsetting. In Fig. 4, b, the defect is disappeared when the transition area slows down. However, the situation is much more complicated in the CEF-Upsetting. Therefore, we must do more simulations to study the effect of geometrical dimensions on deformation in the CEF-Upsetting.



a b

Fig. 4. The deformation of the HS-Upsetting: a – defect deformation, b – no defects deformation

2.4. Barreling Degree Analysis

Upsetting is to force the metal to flow radially downward from the upper anvil, which is a forming method that reduces the height-to-diameter ratio. However, due to the friction between the end face of the workpiece and the flat anvil, the metal near the end face is subjected to tensile stress during radial flow, resulting in a much smaller amount of radial flow than the metal in the middle part of the workpiece. It results in a barreling. Therefore, in order to measure the size of the barreling, the barreling degree is introduced:

$$B = \frac{D_m}{D_{ef}} \times 100\%, \quad (1)$$

where D_m – the middle diameter after upsetting;

D_{ef} – the end diameter after upsetting.

Table1 shows the simulation results of 4 models under the same simulation parameters. It is clear that the CEF-Upsetting, the GEF-Upsetting, the HS-Upsetting all reduced the barreling degree. And their smallest difference of the barreling degree is almost close to 2 %. The smallest barreling degree is 101.8 % which appears in the CEF- Upsetting.

Table 1

The Results of Finite Element Simulation

	Ƞ (%)	D_{ef} (mm)	D_m (mm)	B (%)	Difference (%)
Cylinder-Upsetting	30	111.7	122.9	110.0	10
CEF-Upsetting	30	116.8	119.0	101.8	1.8
GEF-Upsetting	30	115.4	118.7	102.9	2.9
HS-Upsetting	30	111.0	114.0	102.7	2.7

In addition, the concave size has a great influence on barreling degree in the CEF-Upsetting. Therefore, we further study the influence of the depth ratio of the concave(a/D), the ratio diameter of the concave(Dc/D) and the ratio of the reduction (Ƞ) on the barreling degree(B). The CEF-Upsetting structure diagram is shown in Fig. 5.

According to the actual production situation, the value range of each physical parameter is stipulated: the ratio of the groove depth (a/D) is 0.08~0.14, the ratio of the concave diameter (D_c/D) is 0.3~0.6, and the reduction ratio (Ƞ) is 30~50%. The simulation result is shown in Fig. 6. Under the same other conditions, the barreling degree is the smallest when the ratio of the concave depth (a/D) is 0.12. The smaller the ratio of the concave diameter (D_c/D), the smaller the barreling degree. However, when the ratio of the concave diameter (D_c/D) exceeds 0.6, the wall thickness of the annular area on the end face is reduced, and the metal is more likely to flow along the radial outside, forming an irreparable double barreling, which directly affects the performance of the final workpiece. Therefore, the safe upper limit of the ratio of the concave diameter (D_c/D) is less than 0.6. Finally, It is found that there is a certain relationship between the groove size on the end face and the barreling degree (B) after upsetting.

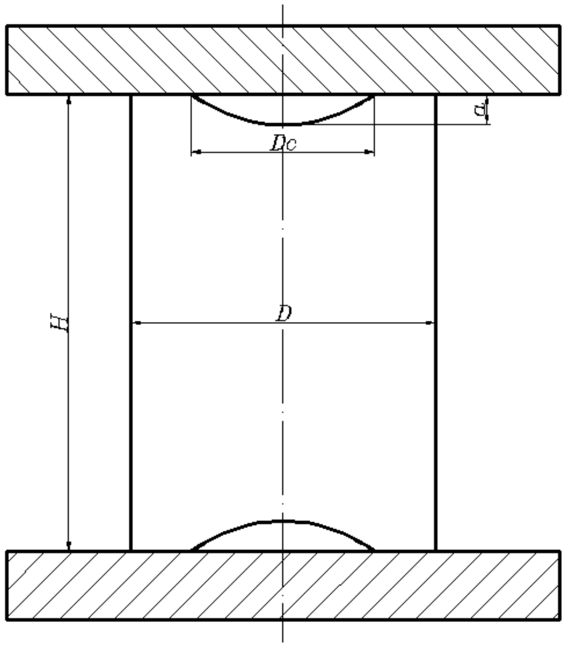


Fig. 5. Structure Diagram of the CEF-Upsetting

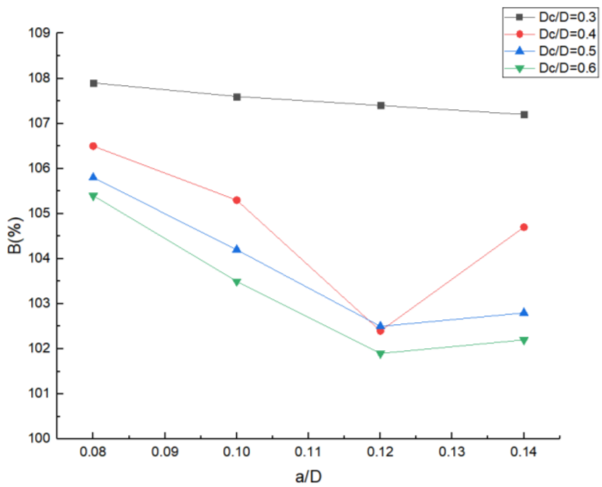


Fig. 6. The Relationship Diagram between B and a/D, Dc/D

3. Fitting Function

Designing the tests plans according to the requirements of orthogonal experiment in Table 2.

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As shown in Fig. 7, using response surface analysis to fit the data in Tab. 2 with quadratic regression equations. The quadratic regression equation is as follows:

$$B = 94.77718 + 1.04964\eta - 32.00694(Dc / D) + 6.24666(a / D) + 0.473955\eta(Dc / D) - 1.4323\eta(a / D) - 154.51354(D_c / D)(a / D) - 0.011435\eta^2 + 21.39864(D_c / D)^2 + 317.36877(a / D)^2. \quad (2)$$

Table 2

Test Plans and Results

	Ƞ(%)	Dc/D	a/D	B(%)
1	40	0.3	0.14	108.9
2	40	0.45	0.11	107.5
3	50	0.45	0.08	110.7
4	30	0.6	0.11	102.4
5	30	0.3	0.11	107.6
6	30	0.45	0.14	103.5
7	50	0.6	0.11	107.5
8	40	0.6	0.08	109.0
9	40	0.3	0.08	110.1
10	40	0.45	0.11	107.5
11	40	0.6	0.14	105.1
12	30	0.45	0.08	106.1
13	50	0.3	0.11	110.1
14	50	0.45	0.14	106.3
15	30	0.6	0.12	101.8

Conclusion

In this paper, the finite element software Deform-2D is used to carry out qualitative and quantitative research on improving the uniformity of upsetting. Concluded as follow:

1. The GEF-Upsetting, the HS-Upsetting and the CEF-Upsetting all play a significant role in reducing the barreling degree. their smallest difference of the barreling degree is almost close to 2%. The smallest difference of the barreling degree is 1.8% which appears in the CEF-Upsetting. The result provides guidance for barreling-less upsetting in the future.

2. The reason for reducing the barreling degree is the metal at the end of the workpiece participates in the deformation. The GEF-Upsetting has uneven end deformation due to the dead zone between the groove and the groove. The HS-Upsetting is defective due to the too large transition between the head and the gauge zone.

3. While the transition between the head and the gauge zone slows down, the defect disappears. The end of the CEF-Upsetting is relatively deformed and has no defects. Since the end face structure of the CEF-Upsetting is relatively simple and easy to study, the influence of the geometrical size of the end of the CEF-Upsetting on the barreling shape has been studied. For analyzing the relationship between the barreling degree (B) and the ratio of the concave diameter (D_c/D) the ratio of the concave depth (a/D), the reduction ratio (Ƞ), Designing orthogonal test. Finally, obtaining the quadratic regression equation to provide theoretical help for barreling-less upsetting.

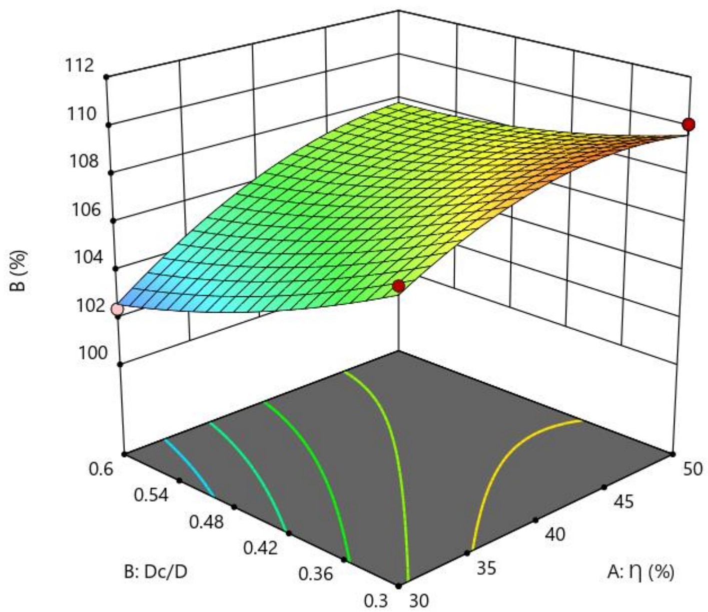

Fig. 7. The Diagram of the Response Surface

References (GOST 7.1 2006)

1. Hong, S. Z. Influence of ingot blank shape on upsetting deformation [Text] / Shenzhang Hong // Hot working technology. – 1984. – No. 3. – P. 42–47. DOI: CNKI: SUN: SJGY.0.1984-03-011.

2. Liu, Z. Simulation Study on Upsetting of Cylindrical Parts Without barrelings [Text] / Z. Liu // Journal of Hebei Institute of Technology. – 1997. – No. 1. – P. 1-6. DOI: CNKI: SUN: HBLG.0.1997-01-005.

3. Sun, Q. J. Measures to reduce the upsetting drum shape and finite element simulation analysis [Text] / Q. J. Sun, G. C. Wang // Journal of Nanchang Institute of Aeronautics and Technology (Natural Science Edition). – 2004. – No. 1. – P. 34-38. DOI: 10.3969/j.issn.1001-4926.2004.01.008.

4. Wang, C. Simulation research on reducing the upsetting drum shape of cylindrical billets [Text] / C. Wang // Forging Equipment and Manufacturing Technology. – 2008. – No. 6. – P. 59-61. DOI: 10.3969/j.issn.1672-0121.2008.06.022.

5. Deng, D. M. Numerical simulation of new upsetting process for conical plate [Text] / D. M. Deng, Z. B. Liu, L. Y. Ni // Forging Technology. – 2005. – No. 3. – P. 14-15. DOI: CNKI: SUN: DYJE.0.2005-03-006.

References (BSI)

1. Hong, S. Z. Influence of ingot blank shape on upsetting deformation. *Hot working technology,* 1984, no. 3, pp. 42-47. DOI: CNKI: SUN: SJGY.0.1984-03-011.

2. Liu, Z. Simulation Study on Upsetting of Cylindrical Parts Without barrelings. *Journal of Hebei Institute of Technology,* 1997, no. 1, pp. 1-6. DOI: CNKI: SUN: HBLG.0.1997-01-005.

3. Sun, Q. J., Wang, G. C. Measures to reduce the upsetting drum shape and finite element simulation analysis. *Journal of Nanchang Institute of Aeronautics and Technology (Natural Science Edition),* 2004, vol. 18, no. 1, pp. 34-38. DOI: 10.3969/j.issn.1001-4926.2004.01.008.

4. Wang, C. Simulation research on reducing the upsetting drum shape of cylindrical billets. *Forging Equipment and Manufacturing Technology,* 2008, no. 6, pp. 59-61. DOI: 10.3969/j.issn.1672-0121.2008.06.022.

5. Deng, D. M., Liu, Z. B., Ni, L. Y. Numerical simulation of new upsetting process for conical plate. *Forging Technology,* 2005, no. 3, pp. 14-15. DOI: CNKI: SUN: DYJE.0.2005-03-006.

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ВИБІР РАЦІОНАЛЬНОЇ ГЕОМЕТРІЇ ЗРАЗКА ПІД ЧАС ВИПРОБУВАНЬ НА СТИСНЕННЯ

В. В. Борисевич, Чжан Сян, Цзинмин Чен

Предметом вивчення в статті є умови під час випробувань на стиснення. Як предмет використовується модель, що симулює фізичні процеси під час випробувань на стиснення. **Метою** є розробка математичної моделі, що дозволяє отримати реальну інформацію про залежність напружень від деформацій під час стиснення. **Завдання:** розробити тривимірну комп'ютерну модель зразка, що знаходиться під стисненням, геометрія якого дозволяє запобігти нерівномірному розподілу напружено-деформованого стану. Використовуваними **методами** є осаджування, що є найпоширенішим методом для випробувань на стиснення. Але завдяки силам тертя на обох кінцях зразка з'являється викривлення середньої зони зразка у вигляді бочкоутворення, що приводить до неадекватних результатів випробування на стиснення. У даній статті міститься кількісне та якісне дослідження фізичних параметрів, які впливають на ступінь бочкоутворення під час осаджування циліндричного зразка. Отримані такі **результати.** Найбільший вплив на зменшення ступеня бочкоутворення мали зразки з піднутренням торців та з головками. Для зразків з піднутренням торців ступень бочкоутворення зменшувався до 101,8 %. Подальший аналіз показав, що обидва методи застосовують подібні принципи для зменшення ступеню бочкоутворення та обидва зменшують ступень бочкоутворення в середній зоні зразка завдяки збільшення деформації у торців. Крім того аналізу піддались вплив деформації в зоні головки на деформацію зони, що підпадає процесу вимірювання. Найбільший вплив має співвідношення величини зони закруглення та розмірів зразка. Також розміри піднутрення мають значний вплив на ступень бочкоутворення під час осаджування. Під час тих самих умов найменший ступень бочкоутворення був при співвідношенні діаметра зразка та глибини піднутрення 0,12, якщо діаметр його не перевищує 0,6 діаметра зразка. Чим менше співвідношення діаметра піднутрення, тим менше ступень бочкоутворення. В кінці було встановлено завдяки проведенню статистичного ортогонального тесту аналітичне співвідношення між ступеня бочкоутворення та геометричними параметрами зразка. **Висновки.** Завдяки знайденим раціональним співвідношенням геометричних параметрів зразка можна отримати інформацію о дійсному напружено-деформованому стані під час осаджування, що можна використати для планування реальних виробничих процесів у майбутньому.

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Ключові слова: осаджування; ступень бочкоутворення; випробування на стиснення; напружено-деформований стан; комп'ютерна модель; симуляція.

ВЫБОР РАЦИОНАЛЬНОЙ ГЕОМЕТРИИ ОБРАЗЦА ВО ВРЕМЯ ИСПЫТАНИЙ НА СЖАТИЕ

В. В. Борисевич, Чжан Сян, Цзинмин Чен

Предметом изучения в статье являются условия при испытаниях на сжатие. В качестве предмета используется модель, симулирующая физические процессы при испытаниях на сжатие. **Целью** является разработка математической модели, позволяющей получить реальную информацию о зависимости напряжений от деформаций во время сжатия. **Задание**: разработать трехмерную компьютерную модель находящегося под сжатием образца, геометрия которого позволяет предотвратить неравномерное распределение напряженно-деформированного состояния. Используемыми методами является осадка, являющееся наиболее распространенным методом испытаний на сжатие. Однако благодаря силам трения на обоих концах образца появляется искажение средней зоны образца в виде бочкообразования, что приводит к неадекватным результатам испытания на сжатие. В данной статье содержится количественное и качественное исследование физических параметров, влияющих на степень бочкообразования при осадке цилиндрического образца. Получены следующие **результаты**. Наибольшее влияние на уменьшение степени бочкообразования имели образцы с поднутрением торцов и с головками. Для образцов с поднутрением торцов степень бочкообразования уменьшалась до 101,8 %. Дальнейший анализ показал, что оба метода применяют подобные принципы для уменьшения степени бочкообразования и оба уменьшают степень бочкообразования в средней зоне образца благодаря увеличению деформации у торцов. Кроме того, анализу подверглись влияние деформации в зоне головки на деформацию зоны, подпадающей процессу измерения. Наибольшее влияние оказывает соотношение величины зоны закругления и размеров образца. Также размеры поднутрения оказывают значительное влияние на степень бочкообразования во время осадки. В тех же условиях наименьшая ступень бочкообразования была при соотношении диаметра образца и глубины поднутрения 0,12, если диаметр его не превышает 0,6 диаметра образца. Чем меньше соотношение диаметра поднутрения, тем меньше ступней бочкообразования. В конце было установлено благодаря проведению статистического ортогонального теста аналитическое соотношение между степенью бочкообразования и геометрическими параметрами образца. **Выводы**. Благодаря найденным рациональным соотношениям геометрических параметров образца можно получить информацию о действительном напряженно-деформированном состоянии при осадке, которую можно использовать для планирования реальных производственных процессов в будущем.

Ключевые слова: осадка; степень бочкообразования; испытание на сжатие; напряженно-деформированное состояние; компьютерная модель; симуляция.

Борисевич Володимир Володимирович – канд. техн. наук, доц., доц. каф. технології виробництва літальних апаратів, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Чжан Сян – асп. каф. технології виробництва літальних апаратів, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Цзинмин Чен – професор, лектор, Південо-західний Політехнічний Університет Пінїнь, Китай.

Volodymyr Borysevych – PhD, Associate Professor, Technology of Aircraft Manufacturing Department, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: v.borisevich@khai.edu, vladimir_borys@yahoo.ca.

Xiang Zhang – PhD student, Technology of Aircraft Manufacturing Department, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: zhangxiang930522@gmail.com, ORCID: 0000-0001-6607-4270.

Jingming Chen – Master, Lecturer, Northwestern Polytechnical University Ming de College, China,
e-mail: Chenjingming0@163.com, ORCID: 0000-0002-9353-1665.