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Numerical simulation of cold forging process with enclosed dies to avoid folding defect in forming shape

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Abstract. *In the precision forging industries, improving product quality and reducing product cost are important cases. Enclosed-die forging is one of the precision forging processes. In this paper, the cold forging process in the enclosed dies by using kinematical mechanism to create precision parts is considered. The numerical simulation techniques by using the rigid-plastic finite element method (FEM) as software QForm 2D have been applied to investigate defect as a folding defect in this paper. Based on the finite element simulations, forming characteristics such as deformation patterns (gridlines distortion), distributions of effective strain and stress at several stages of process as single-ended and double-ended with different forming parameters to avoid folding defect in cold forging process have been investigated. The lower die velocity vs. geometric ratio by using this numerical simulation method has been determined.*

Keywords: *Cold forging, enclosed die, material flow, folding defect, numerical simulation, stress-strain state*

Introduction

In recent years, metal forming processes play an important role in manufacturing industries. Forging is on of the main metal forming processes having industrial applications for producing different parts with various shapes. Product quality, cost and time to market are three overriding issues in metal forming industry. Defects occurring as folding defect during metal forming processes sometimes are caused. It is very important and necessary to control material flow during the process to avoid the formation of folding defect. There are several basic categories of forging processes including cold, warm and hot. Computer aided design, manufacturing and engineering techniques have been gradually applied to design and analysis of metal forming processes such as the cold, warm and hot forging processes. On the other hand computer aided simulation techniques in metal forming reduce the cost and time of process design. Finite element method (FEM) to design and analysis processes has been actively introduced in metal forming. By using this method can been observed theoretical results such as material behavior, distribution of stress and strain and etc. In the production of industrial parts with complex geometries, the cold forging process provides both economical and technological advantages compared to other metal forming processes. Near net shape quality, excellent surface finished and improved mechanical properties are the most important advantages by using cold forging process. Enclosed die forging with room temperature is type of precision cold forging process and also an effective process in reducing manufacturing costs. In this process, the cylindrical solid or tubular billet is located in the die cavity and is squeezed by multiple rams. The billet is compressed with one or two opposite rams movement and the billet material fills the die cavity [1-14].

Method of Analysis

Numerical solution and method such as finite element (FE) is an important method to analysis material behavior and stress-strain state in metal forming processes especially in enclosed die forging process. In this study, a rigid plastic finite element program QForm 2D was used to investigate folding defect for cold forging process in enclosed dies.

Purpose of Investigation

In this paper, to create precision parts in cold forging process, enclosed dies have been used. Based on the finite element simulations, forming characteristics such as deformation patterns (gridlines distortion), distributions of effective strain and stress at several stages of process with different forming parameters and also to predict and avoid

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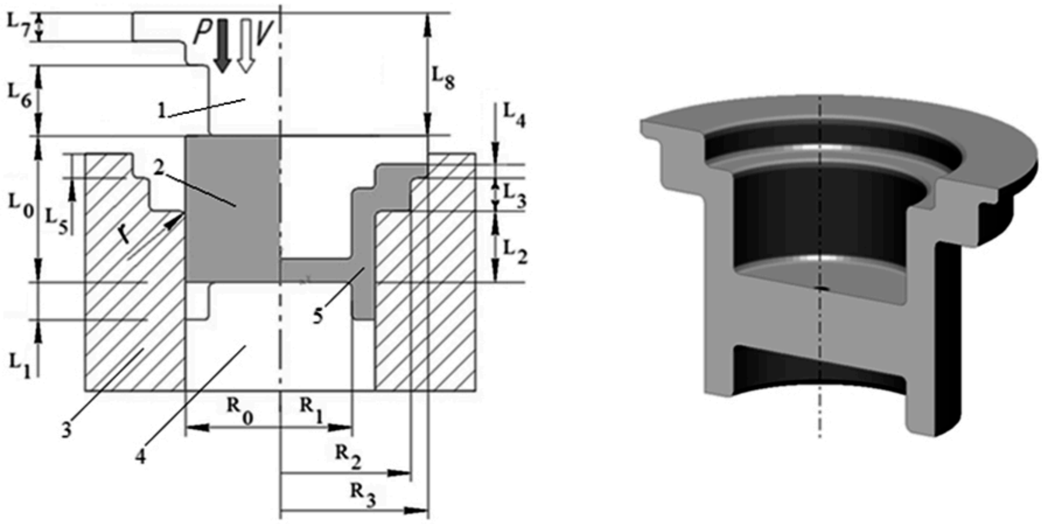
folding defect in cold forging process have been investigated by using this theoretical simulation method.

Cold Forging Process

The die scheme, die geometries, billet dimensions and the formed part for cold forging process with enclosed dies are shown in Fig. 1. A cylindrical billet is considered. The die geometry parameters, billet dimensions and power mode parameters are as follows: R_0 – the radius of billet (R_0= 20mm), R_1= 15mm, R_2= 27.5mm, R_3= 31mm, L_0 – the billet height (L_0= 30mm), L_1= 8mm, L_2= 15mm, L_3= 7mm, L_4= 2.5mm, L_5= 5mm, L_6= 15mm, L_7= 6mm, L_8= 26mm, r – the punch, lower die and mandrel tip radiuses (r=1mm), V – punch velocity (V=1mm/s), P – punch load, The friction factors between the billet and tools are constant (Zibel's law, μ=0.08).



a *b*

Fig. 1. Scheme of cold forging process with enclosed dies (a) and formed part (b), 1 – punch, 2 – billet, 3 – lower die, 4 – mandrel, 5 – formed part

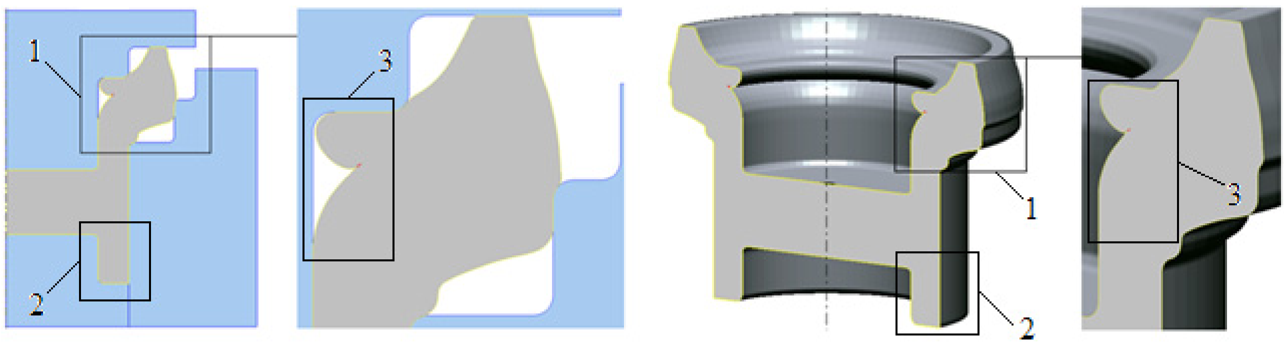
Material Property

In this study, the material used for the simulation is AA 6060 aluminum alloy. The relationship between flow stress and effective strain for AA 6060 aluminum alloy can be approximated by [15]:

$$\overline{\sigma} = 191.55\varepsilon^{-0.202} \text{ (MPa)} \quad (1)$$

Analysis of Cold Forging Process

The accurate design of cold forging process to create a precision part is very necessary and important in manufacturing processes. In this investigation process some tools such as punch, lower die, mandrel and also billet have been used. Simulation based on the finite-element (FE) method is considered. The finite element software is used a direct iteration and Newton-Raphson methods to solve the nonlinear equations. During the simulations by QForm2D, it is seemed that the billet is rigid-plastic body and punch, lower die and mandrel are all rigid bodies. In the cold forging process, billet and tooling temperatures are room temperature. Material flows and dies cavity filling are very important in this process. The material flow behavior and the influence of various factors involved in the process were explored. During the cold forging process with an axisymmetric billet, a movable punch applies force on billet material and the material flows to form the formed part in dies cavity. A finite element simulation is developed to study the defect formation mechanism. Fig. 2 shows the material behavior in cold forging process. It is observed that in the forming



a *b*

Fig. 2. Folding defect in cold forging process: die scheme (a), formed part (b), 1 – upper section, 2 – lower section, 3 – folding defect

process appears a defect as a folding defect on the material flow (Fig. 2). In this study, the material flow behavior has been included with combined behaviors as forward, backward and radial flows. There are two major stages for filling dies cavity. First stage, when the punch presses the billet, the material under the punch moves down and up. Die cavity in lower section faster than upper section fills. After that the material flow under punch completely moves up, second stage begins. In second stage a critical inner curved surface in upper section appears. The punch movement continues down and the flow pattern further develops a defect as folding defect that shown in Fig. 2. In this process study to predict and avoid defect as a folding defect is very important and necessary to create precision parts.

Based on the revealed folding defect, it is therefore necessary to design a kinematical mechanism by using finite element simulation to avoid defect as a folding defect. In this investigation in order to avoid folding defect and to make new material flow and to create a precision part without folding defect has been used a movable lower die in dies component. Fig. 3 and Fig 4 present the simulation results of material flow behavior. Deformation patterns (gridlines distortion) (Fig. 3), distributions of effective strain and stress (Fig. 4) with the movable punch and the movable lower die in single-ended and double-ended cold forging processes are shown. In these figures present two forming stages in the deformation process based on velocities of movable punch and lower die. The first stage (Fig. 3, 4 – a), the punch moves down and presses the billet with a certain and constant velocity (V=1mm/s), the punch stroke reaches 15.7 mm. The material flow moves in backward, forward and radial directions. The second stage (Fig. 3, 4 – b), when the stroke of punch reaches this position (S=15.7mm), the punch and lower die together move. The punch moves down and the lower die moves up. In this stage punch velocity is previous velocity (V=1mm/s) and the lower die velocity is a certain and constant velocity ($V^{/}$=0.75mm/s). Based on these stages and design a kinematical mechanism a precision part without defect as a folding defect is observed. The influences of the high positions (parameters h) in Fig.5 to create different precision parts are studied. It is observed from these figures that with different lower die velocities can be created precision parts with different geometric parameters.

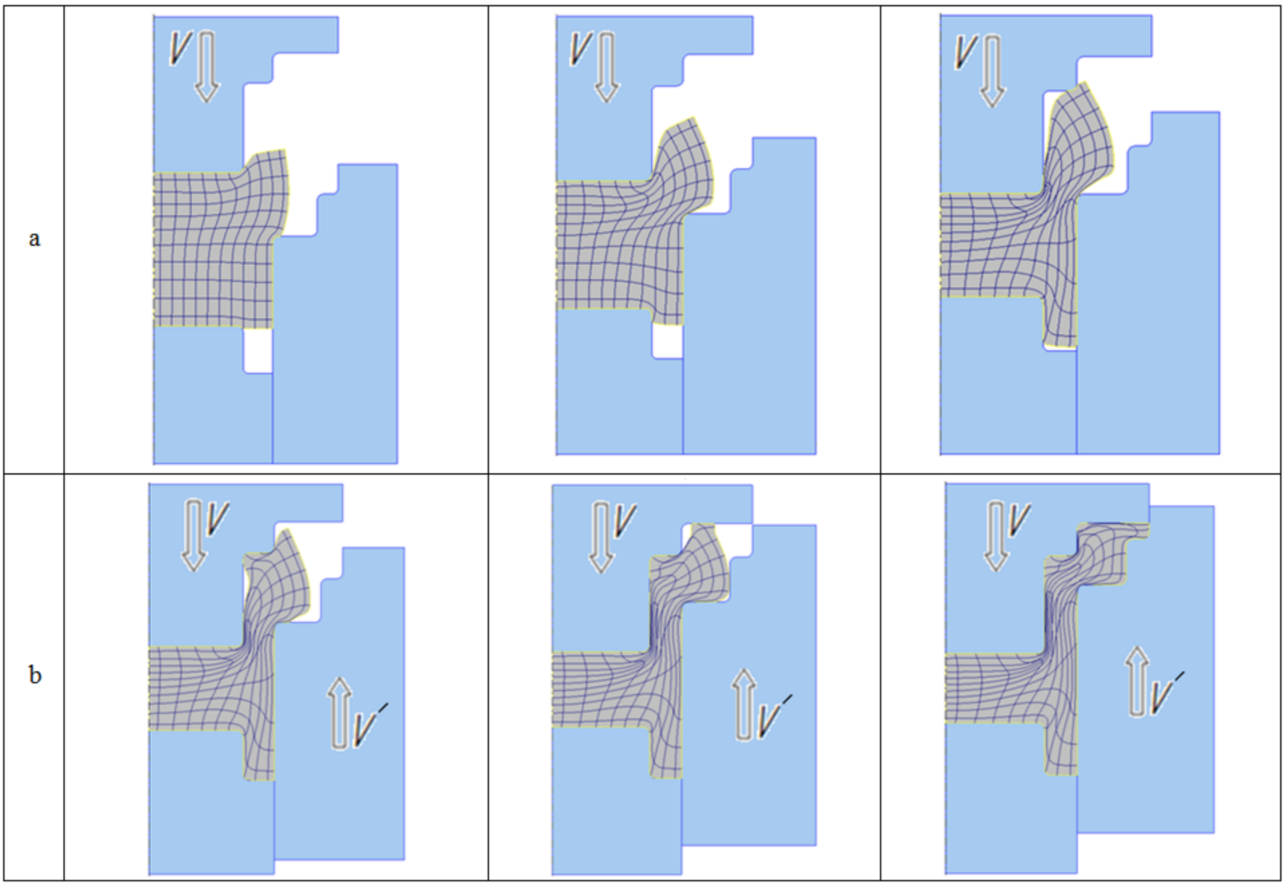


Fig. 3. Deformation patterns (gridlines distortion) in single-ended (a) and double-ended (b) cold forging processes

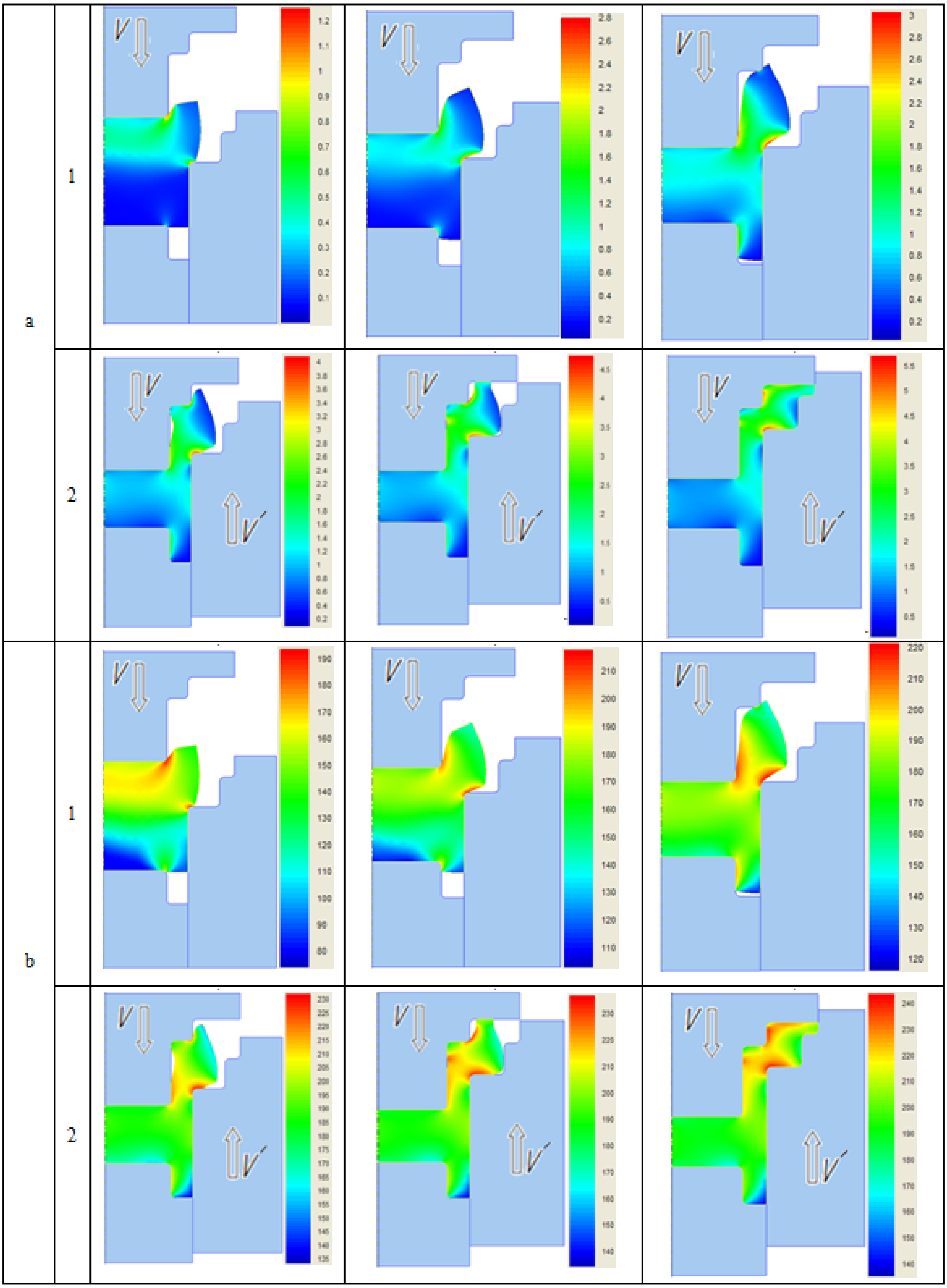
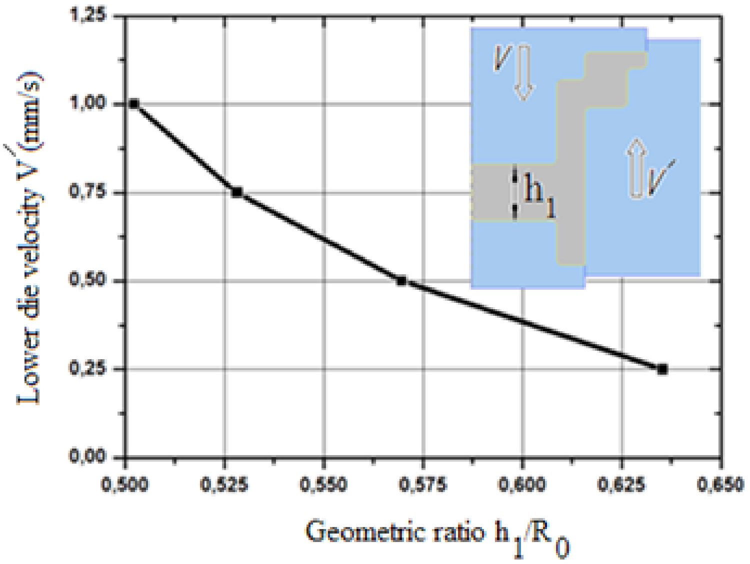
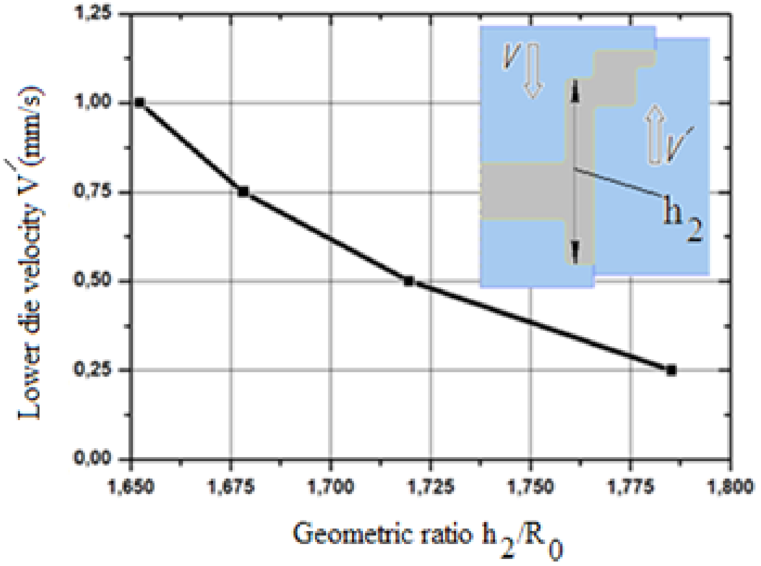


Fig. 4. Distributions of effective strain (a), stress, MPa (b) in single-ended (1) and double-ended (2) cold forging processes

a



b



c

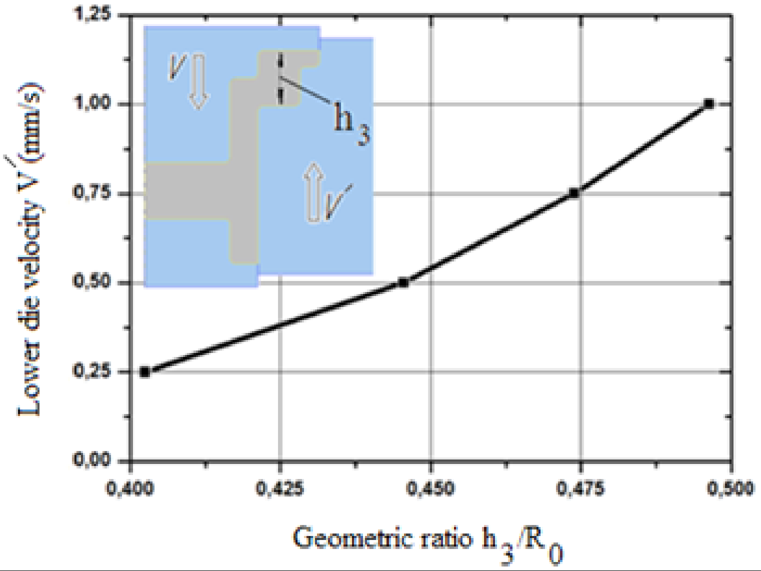


Fig. 5. The lower die velocity vs. geometric ratio h_i/R_0: a – h_1/R_0, b – h_2/R_0, c – h_3/R_0

Conclusions

In this study, the cold forging process in enclosed dies by using a numerical simulation as software QForm 2D based on finite element method to investigate defect as a folding defect is considered. The material behavior by kinematical mechanism to avoid folding defect is investigated. Deformation patterns (gridlines distortion), distributions of effective strain and stress with the movable punch and the movable lower die in single-ended and double-ended cold forging process are shown. The lower die velocities vs. various geometric ratios as determined from the finite element simulations. It is observed from these diagrams that with different lower die velocities can be created precision parts with different geometric parameters.

Численное моделирование процесса холодной объемной штамповки в закрытых матрицах для устранения дефектообразования при формоизменении

П.Б. Абхари

Аннотация. *Важными элементами точной объемной штамповки в промышленности являются повышение качества продукции и снижение стоимости продукта. Штамповка в закрытых матрицах является одним из методов точной объемной штамповки. В этой статье рассматривается процесс холодной объемной штамповки в закрытых матрицах с использованием кинематического механизма для создания прецизионных деталей. Метод численного моделирования, с использованием метода жестко-пластических конечных элементов (МКЭ), на основе программного обеспечения QForm 2D, был применен для исследования такого дефекта как зажим. На основе моделирования конечных элементов, сформированы характеристики, такие как деформации (искажение делительной сетки), распределение интенсивности деформаций и напряжений на нескольких этапах процесса при односторонней и двухсторонней подачах с различными параметрами процесса для устранения дефекта в виде зажима в процессе холодной объемной штамповки. На основе метода численного моделирования построены графики зависимости скорости нижней матрицы при разных геометрических соотношениях параметров процесса.*

Ключевые слова: *холодная штамповка, закрытая матрица, течение материала, зажим, численное моделирование, напряженно-деформированное состояние*

Чисельне моделювання процесу холодного об'ємного штампування в закритих матрицях для усунення дефектоутворення при формозміні

П.Б. Абхарі

Анотація. *Важливими елементами точної об'ємного штампування в промисловості є підвищення якості продукції та зниження вартості продукту. Штампування в закритих матрицях є одним з методів точної об'ємного штампування. У цій статті розглядається процес холодного об'ємного штампування в закритих матрицях з використанням кінематичного механізму для створення прецизійних деталей. Метод чисельного моделювання, з використанням методу жорстко-пластичних скінченних елементів (МСЕ), на основі програмного забезпечення QForm 2D, був застосований для дослідження такого дефекту як зажим. На основі моделювання скінченних елементів, сформовані характеристики, такі як деформації (викривлення ділильної сітки), розподіл інтенсивності деформацій і напружень на декількох етапах процесу при односторонній і двосторонній подачах з різними параметрами процесу для усунення дефекту у вигляді зажиму в процесі холодного об'ємного штампування. На основі методу чисельного моделювання побудовані графіки залежності швидкості нижньої матриці при різних геометричних співвідношеннях параметрів процесу.*

Ключові слова: *холодна штамповка, закрита матриця, течія матеріалу, зажим, чисельне моделювання, напружено-деформований стан.*

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