RECOMMENDATIONS FOR SELECTION OF PARAMETERS OF COGGING IN V-DIES

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ODPORÚČANIE PRE VÝBER PARAMETROV PREDKOVANIA (NA BLOKY) VO V- MATRICIACH

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Abstrakt

Predkovanie (na bloky) v tvarovaných matriciach (napr. V-matriciach, kovacej matrici, kombinácii V- matrice a rovinnej matrice) sa značne odporúča v prípadoch, keď kovanie ingotov sa robí u materiálov s nízkou tvarovateľnosťou. Tvar zápustiek má však určité obmedzenia, ktoré sa musia zohľadniť v priebehu rozvoja vývoja vhodného procesu kovania. Návrh režimu kovania nemôže byť založený len na účinnosti rozmerových zmien materiálu. Pre získanie vysokej kvality konečného produktu musí dôjsť k eliminácii štruktúry defektov v stave liatom v priebehu procesu predkovania. Metalurgické defekty sú lokalizované zväčša v blízkosti osovej časti ingotu. Preto také varianty parametrov predkovania by mali byť zvolené, aby vytvorili veľkú deformáciu jadra ingotu v podmienkach trojosového stavu napätí. Stupeň záberu, individuálna redukcia výšky a pomer strán (štíhlosť) obrobku sú parametrami predkovania, ktoré majú rozhodujúci vplyv na lokálne mechanické stavy v deformačnej zóne, rovnako ako účinnosť elongácie. V príspevku sú prezentované výsledky numerickej simulácie predkovania vo V-matriciach (s 135° uhlom medzi ich pracovnými povrchmi), ktoré boli uskutočnené s cieľom zistenia vplyvu spomínaných parametrov procesu na lokálne mechanické stavy v deformačnej zóne. Výsledky výskumu spolu so závermi pochádzajúcimi z relevantného literárneho prehľadu umožnili stanoviť rozumné odporúčania pre výber vhodných parametrov predkovania v analyzovanom type matrice.

Abstract

Cogging in shaped dies (e.g. V-dies, swage dies, V-die and flat-die combinations) is highly recommended when forging ingots are made of materials with poor formability. However, the dies shape imposes some limitations that must be taken into account during development of the proper forging procedure. The cogging pass schedule design cannot be based only on efficiency of the stock dimension changes. To achieve the high quality of a final product, the as-cast structure defects have to be eliminated during cogging process. Metallurgical defects are localized mostly near the ingot centreline. Therefore, such variants of cogging parameters should be selected that produce large deformation of the ingot core under triaxial compressive state of stress. The bite ratio, the individual reduction in height and the workpiece aspect ratio are the cogging parameters that have the most crucial influence on the local mechanical states in the deformation zone as well as the elongation efficiency. This paper presents some results of numerical simulations of cogging in V-dies (with 135° angle between their working surfaces) that have been conducted in order to find out the effect of the mentioned process parameters on the local mechanical states at the deformation zone. Research results together with conclusions coming from the relevant literature review have allowed to establish the rational recommendations to select the appropriate parameters of cogging in the analyzed type of dies.

Key words: open-die forging, cogging, drawing out, V-dies, state of stress

1. Introduction

The main goal of the cogging process is elimination of numerous metallurgical defects, e.g. voids, localized mostly near the ingot centreline. Otherwise, these defects may cause damage of the final product during further use. In order to consolidate internal voids and porosity, extensive compressive deformation of the ingot core is necessary. The state of stress in the deformation zone is strongly dependent on the process parameters (such as the bite ratio, the reduction in height and the workpiece aspect ratio) and the dies shape. For cogging a stock made of a material with poor formability, it is recommended to use shaped dies. According to many researchers [1,2,3], the V-dies with 135° angle between their working surfaces are the most adequate for cogging the typical forging ingots that have the polygonal cross-section.

The most convenient way to assess the effect of cogging process parameters on the local mechanical states in the deformation zone is the finite element analysis. The numerous research on cogging process, based on this approach, can be found in the relevant literature [4-10]. The selected results of 3D finite-element simulations of cogging in the mentioned type of V-dies are described in the further part of this paper.

2. Research method

Numerical simulations of cogging were conducted by means of Forge3 – a 3D FEM software dedicated for metal forming applications. A numerical model and research schedule was determined on the basis of industrial data, plastometric torsion tests and the relevant literature review. Details of the adopted approach are described in [11]. A stock had the octagonal cross-section and was made of D2 tool steel. The viscoplastic model of material and the rigid model of dies were used. At first, the thermal simulation was performed to obtain the initial temperature gradient inside the stock. This corresponds to the cooling of a stock, previously heated to 1050°C, during 2-minute transportation from the furnace to the press in the ambient temperature of 25°C. The calculated temperature range between 990°C (at the surface) to 1050°C (at the core) obtained from the thermal simulation coincides with the temperature measurements with a pyrometer. The numerical results of some thermo-mechanical simulations were also validated with the data measured in the industrial process, obtaining the satisfactory accuracy [11,12]. The accepted model was then used in the further simulations. Various combinations of process parameters were analyzed. The ranges of these parameters as well as a shape and dimensions of V-dies are presented in the Fig. 1. The Tresca friction law was used for description of the friction conditions at the interface between the stock and the dies. The assumed value of friction factor equalled 0,4 [13,14]. The data needed for calculation of heat transfer in the considered configuration are given in the Table 1.

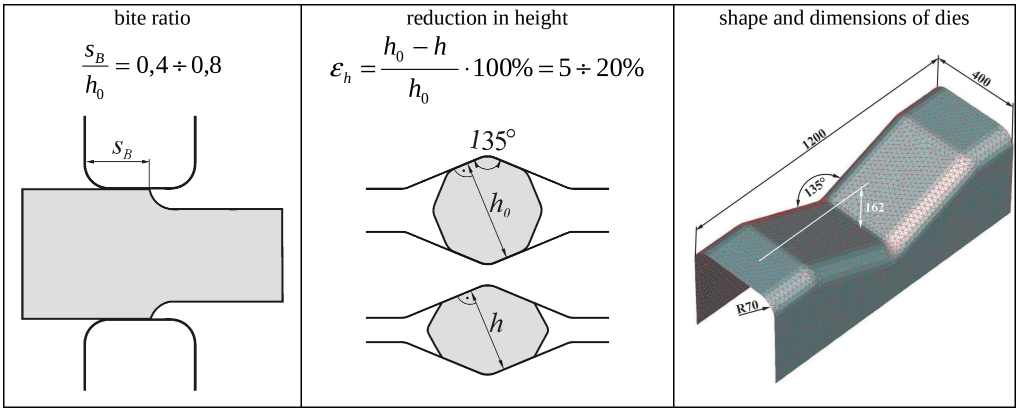

Fig.1 Ranges of cogging parameters and the geometry of V-dies used in simulations

Table 1 Values of thermal and physical parameters used in the simulations [15,16,17]

Parameter	Value	
density ρ	7500	$kg \cdot m^{-3}$
heat capacity c_p	750	$J \cdot (kg \cdot K)^{-1}$
thermal conductivity k	23	$W \cdot (m \cdot K)^{-1}$
coefficients of heat transfer: - to the dies (α_1) - to the air (α_2)	10000 6	$W \cdot (m^2 \cdot K)^{-1}$ $W \cdot (m^2 \cdot K)^{-1}$
emmissivity ε_r	0,8	-
dies temperature T_k	400	°C
ambient temperature T_{ot}	25	°C

3. Research results

The obtained simulation results confirm a significant effect of the cogging parameters on the material flow and the local state of stress. The diagrams shown in the Fig. 2 present the effect of the bite ratio on changes of the stress triaxiality factor and normal stress components at the centre of a deformation zone for passes in which the initial cross section of a stock has the regular octagonal shape. It can be observed that for the bite ratios smaller than 0,5, triaxial compression cannot be obtained (the longitudinal normal stress component remains tensile even for the great reductions in height – see Fig. 2b). For the bite ratio of 0,5 elimination of the tensile stresses at the billet centre is already possible, but it requires reductions exceeding 15%. The higher the bite ratio, the quicker transition to the triaxial compressive state of stress. For the bite ratio of 0,7, the reduction of only 5% is sufficient to achieve it. However, research results recently published on this topic [9,10] indicate that the increase of the bite ratio behind 0,7 does not influence the efficiency of void closing, so it only causes the unnecessary increase of spread and forging force. Hence, the conclusion can be made that the bite ratio of 0,5÷0,7 and reductions higher than 10% are sufficient enough to obtain the expected state of stress at the centre of a deformation zone.

Avoidance of the tensile stresses is particularly important in the initial phase of cogging, due to poor formability of the as-cast structure. However, application of the bite ratios and reductions within the recommended ranges can sometimes be hard to achieve in this phase, due to limited capacities of the available presses. To avoid exceeding the press capacity one has to reduce the bite ratio or the reduction in height or use the flat dies instead of the shaped ones (the force needed to realize cogging in V-dies is significantly higher than the force in the same cogging variant performed in the flat dies). In order to find out the best alternative, the two variants of cogging in V-dies and, additionally, the one case of cogging in flat dies have been compared. Every variant required the similar forging force that was close to the capacity of considered press (20 MN).

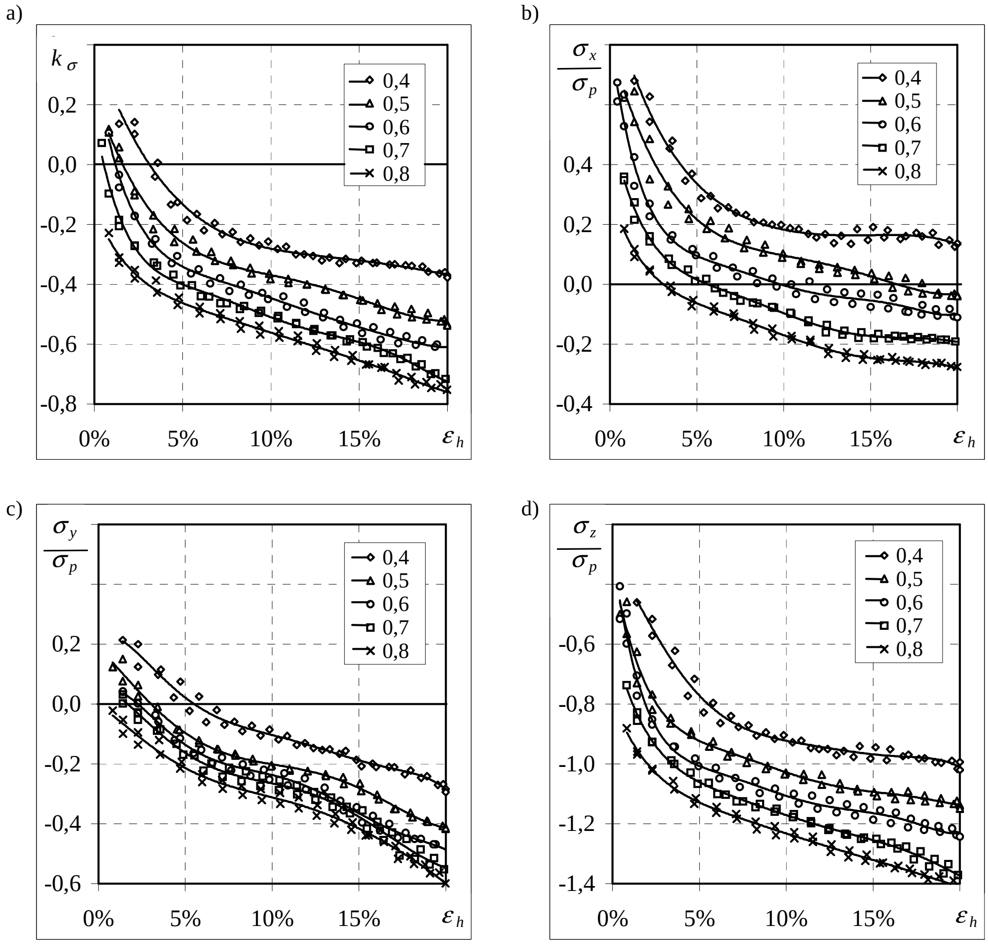

Fig.2 Changes of the stress triaxiality factor (a) and normal stress components: longitudinal (b), transverse (c) and vertical (d) at the centre of a deformation zone, for various bite ratios within the range of 0,4÷0,8

Changes of the longitudinal and transverse normal stress components at the centre of the deformation zone in the analyzed variants are presented in the Fig. 3. An advantage of the V-dies over the flat ones is manifested by a much quicker reduction of the transverse tensile stress (Fig. 3b). Moreover, during cogging in V-dies, smaller are the regions beyond the direct impact of dies where the longitudinal tensile stresses occur [11]. The additional benefit of cogging in the V-dies comes from the increase of elongation in spite of the smaller reduction. Considering variants with the V-dies, the more favourable state of stress occurred for higher bite ratio but smaller reduction.

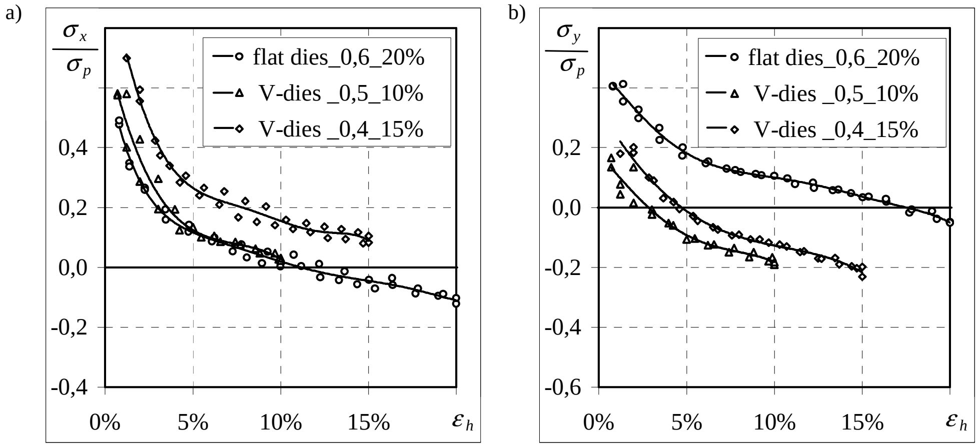

Fig.3 Changes of the longitudinal (a) and transverse (b) normal stress components at the centre of the deformation zone, for cogging variants of similar forging force (ca. 19 MN). Legend designations, respectively: die type, bite ratio, reduction

It was also found out that the workpiece aspect ratio (a quotient of the height and the width before each pass) has the essential effect on the local mechanical states in the deformation zone [11,18]. The typical cogging pass schedule comprises two kinds of passes (Fig. 4a). The regular octagonal cross-section (for which the aspect ratio equals 1) is "flattened" in odd passes. This causes that a workpiece before the even passes has the aspect ratio higher than unity. After even passes the cross-section becomes regular again. The changes of stress state presented in Fig.5 prove that local mechanical states differ significantly in the subsequent passes of this cogging technology. It is obvious that higher reductions in the odd passes cause higher spread and, therefore, higher aspect ratio in the even passes. The higher the initial aspect ratio, the more dangerous is the initial phase of deformation. Longitudinal and transverse tensile stresses occur in a large part of the deformation zone. A way to improve the state of stress is by using higher bite ratio in the even passes than in the odd ones (if the die with is sufficient enough). It is possible because, for the same bite ratios, the forging force in the even passes is significantly smaller than in the odd ones.

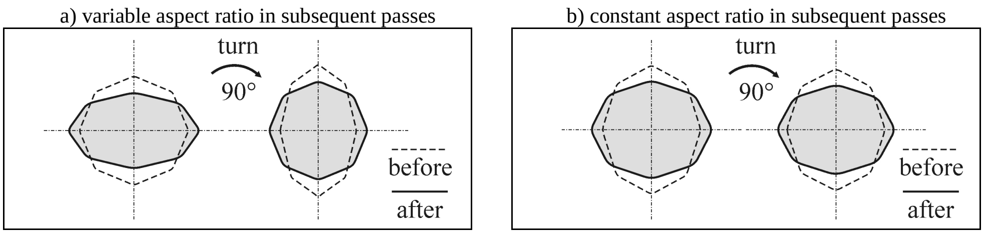

Fig.4 Types of the cogging pass schedule

Considering the state of stress near the stock centreline, cogging with constant aspect ratio (Fig. 4b) seems to be the better solution for materials that exhibit poor formability. Such type of the pass schedule enables to achieve similar state of stress in subsequent passes. The initial aspect ratios are considerably smaller than in the even passes of the cogging schedule presented in the Fig. 4a. Therefore, transition of the tensile stresses near the stock centre into the compressive ones takes place for much smaller reductions.

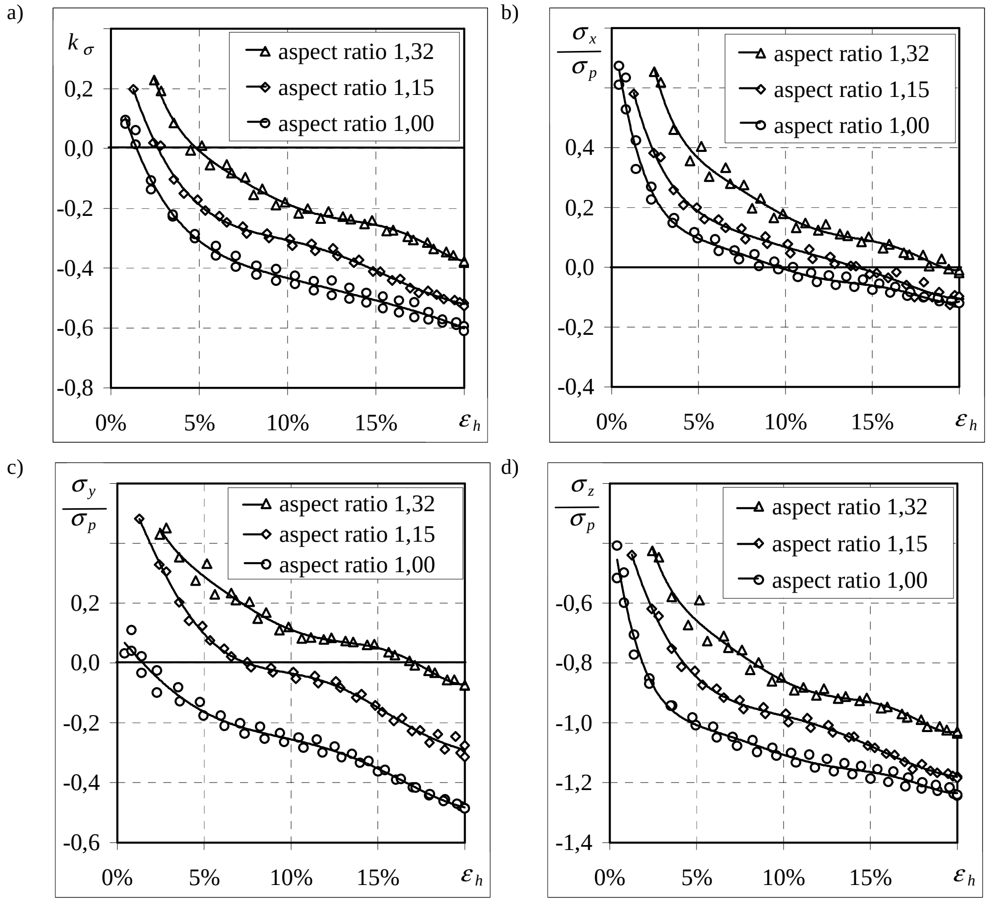

Fig.5 Changes of the stress triaxiality factor (a) and normal stress components: longitudinal (b), transverse (c) and vertical (d) at the centre of a deformation zone, for various aspect ratios. Results obtained for the bite ratio of 0,6

4. Summary

Taking into account the results of conducted numerical research, the industrial experience and the literature review, the general recommendations have been formulated for selection of parameters of cogging in V-dies.

It is obvious that the quality aspect should be considered as the principle criteria for determination of the proper cogging technology. For that matter, the selected procedure should allow achieving favourable, compressive state of stress in the workpiece volume. Basing on this approach, two phases of cogging in V-dies can be distinguished. The duration of each phase depends on the process constraints, i.e. the press capacity and the die width.

It frequently happens in the industrial practice that the appropriate combination of process parameters cannot be applied, due to large cross-sections of forging ingots. The reason is that the forging force required exceeds the press capacity. In such cases, among the feasible cogging variants those with higher bite ratio are preferred rather than those with higher reduction. First of all, it is recommended to select the bite ratios not smaller than 0,5. If possible, individual reductions should be higher than 10%. As the stock cross-section is reduced during subsequent passes, both parameters should be progressively increased in order to achieve the compressive deformation near the workpiece centreline as soon as possible.

When the forging load and dies geometry are not the constraints, the maximum permitted individual reductions in height should then be used, taking into account the strain to fracture characteristics of a formed material. One can assume that the individual reductions of up to 25% and the bite ratios of up to 0,7 are sufficient. The further increase of the bite ratio causes only small improvement of the stress state. Besides, it requires the higher forging force, causes larger non-uniformity of strain and larger spread as well as has no significant effect on the efficiency of consolidation of voids localized near the workpiece centreline.

When cogging is conducted according to the pass schedule which assumes the variable aspect ratio in subsequent passes, it is recommended to apply the higher bite ratio in the even passes than in the odd ones, in order to improve the state of stress around the stock centreline. For materials with poor formability, cogging with the constant initial aspect ratio seems to be the better solution - it enables to achieve the constant cogging parameters and similar state of stress in subsequent passes.

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