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NUMERICAL ANALYSIS OF FRICTION INFLUENCE ON THE TRANSVERSE WELDING PHENOMENON IN THE FORWARD EXTRUSION PROCESS

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There is often a need to join billets being extruded in the forward extrusion processes in order to preserve the continuity of manufacturing of products. The primary problem connected with joining while extruding is to ensure the required state of stress, deformation and temperature assuring a good weld quality. The paper contains numerical analyses of the transverse joining processes of billets in the course of forward extruding. The impact of the friction between welded objects on the material flow in vicinity of the joints is analyzed. A numerical method for determination of the weld length at the longitudinal section, by assuming the homogeneity of the strain rate at both sides of the joined elements contact line, is proposed. Three cases of the forward extruding are analyzed. Two friction shear factors equal to $m = 0.4$ and $m = 0.9$ at the billets interface are modelled for each case and weld the lengths at the longitudinal sections are presented. In addition, distributions of the flowing material velocities and effective strains in the weld vicinity are added for all tested processes.

Keywords: extrusion, welding criteria, FE analysis

1. Introduction

In the metal profiles forward extrusion processes, there are often applied joining operations for the extruded items. There are two methods of plastic joining during extrusion: transverse joining – applied in order to ensure the production continuity and longitudinal one – used to connect the extruded material streams.

Piwnik (2010) pointed that the primary problem connected with welding while extruding is to ensure the required state of stress, deformation and temperature assuring good quality of the weld. He also noted that good weld quality can be achieved by applying the optimal shape of the welding chamber, appropriate material temperature, load and punch velocity.

Many criteria for the estimation of welds quality have been proposed. Akeret (1972) considered the only maximum contact pressure as the discriminating welding parameter. Criteria for transverse and longitudinal welding proposed by Plata and Piwnik (2000) assume that the adhesion process has a time and rheological aspect. The sequent criterion was proposed by Donati and Tomesani (2004) in which the velocity is introduced to the longitudinal welding Piwnik criterion mentioned above. Based on these criteria, it can be suggested that the quality of the welded product will increase if the necessary criteria by Piwnik (2010) are ensured:

- quality of the contact surface;
- normal stress;
- shear stress;
- length of the stream lines;
- time of the material particle presence in the field of high normal stress.

Welding processes in conjunction with FE simulations of extrusion have already been used. Li *et al.* (2003) presented mechanisms of the transverse welds formation with the aim of minimising the transverse weld length of the extrudate. Bariani *et al.* (2006) realized an experimental model to analyze the welding processes that can occur in the porthole die extrusion. Ceretti *et al.* (2009) described the implementation of the Piwnik longitudinal welding criterion in DEFORM 2D environment. Piwnik *et al.* (2011) suggested that initially formed billets improve welding conditions. Numerical analysis allows to determine velocities and stresses distributions in the plastic joining area and, by these, to determine the quality of the weld. However, the problem of determination of the extruded billets welded surface size still remains.

The paper presents numerical analyses of the transverse welding conditions during forward extruding. The influence of contact friction between the joined objects on the material flow in the vicinity of joints is specified. A numerical method for determination of the welded area by assuming the homogeneity of the strain rate at both sides of the joined elements contact line is proposed. Three cases of forward extruding are presented. Two friction shear factors ($m = \tau_f/k$; where: τ_f – frictional stress; k – shear yield stress) at the billets contact surface $m = 0.4$ and $m = 0.9$ are modelled for each case. The analyzed cases are:

1. Extrusion of cylindrical billets through a rectangular die
2. Extrusion of cylindrical billets through a conical die;
3. Extrusion of cylindrical billets through a rectangular die, where the upper one had a spherically shaped face.

For all tested processes, the velocities and strain effective distributions in the advanced material flow phase were found. For the first case of tested processes, the punch pressures obtained during extrusion were generated and the punch works were and compared.

2. Numerical analysis of welding during extrusion

2.1. Analysis assumptions

Axisymmetrical geometry of the investigated processes allows consideration of one half of the billet only, reducing thus the calculation time. To carry out simulation processes, the commercial code DEFORM 2D was used. As well as the die, the container and punch were treated as rigid bodies. In all tested cases, the ratios between the container and die cross sections areas were equal 4:1. At the tool-workpiece interface, a constant friction shear factor $m = 0.4$ was assumed. The billets material was considered as plastic with the strain hardening characterized by the stress-strain curve shown in Fig. 1. The treatment temperature was eual to $20°$C. For the effective stress and strain description, the program uses the Huber-Mises yield criterion. The velocity distribution is found by the minimum work rate principle which predicts the lowest work rate.

In the paper, the concept of the estimation of the welded area size for extruded billets is presented. This approach assumes that the joining of extruded elements takes place, when the strain rate homogeneity occurs at both sides of the contact line, and these fields are analogous to the strain rate distribution present during extruding of a single billet with the other conditions of welding remained.

2.2. Welding in the rectangular die

A view to a numerical simulation of transverse joining of two cylindrical billets forwardly extruded through a rectangular die is presented below (Fig. 2a). In the case of extruding with the friction shear factor $m = 0.4$ at the billets contact (Fig. 2b), the presence of a small void in the middle of the contact line was observed. When the friction shear factor was equal $m = 0.9$ (Fig. 2c) the full fill was obtained.

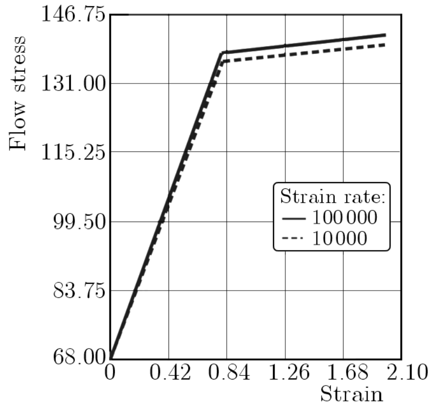

Fig. 1. Stress-strain curve of the deformed material

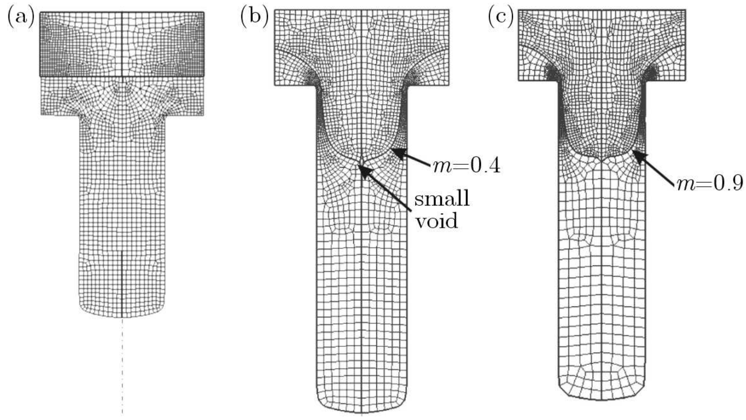

Fig. 2. Joining during forward extruding through a rectangular die: (a) view of billets before joining, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$ at the billets interface

The model of axisymmetrical welding extrusion through a rectangular die revealed, for the friction factor $m = 0.9$, the moment of connection when the homogeneity of the strain rate at both sides of the contact curve appears in the earlier phase of flow than at $m = 0.4$ (Figs. 3b and c). The moment of welding completion appears to be on a similar level of the flow process in both tests (Figs. 4a and b). The investigated model showed also the lack of connection at a large area of the central part of the extruded product.

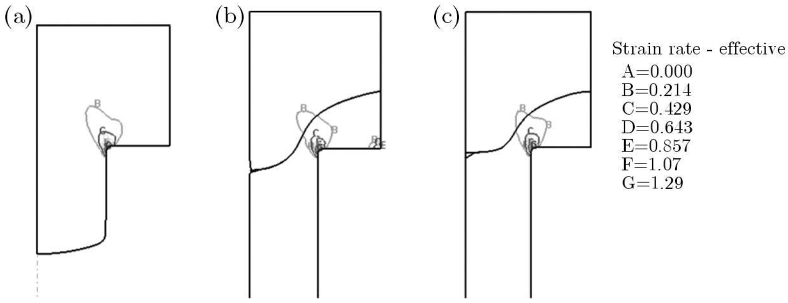

Fig. 3. Strain rates describing the beginning of weld creation during axisymmetrical forward extrusion through a rectangular die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

During forward extrusion through a rectangular die, the dimensionless punch pressures q equal $q = P/(S_0 R_e)$, where: P – extrusion force, S_0 – sample face area before extrusion, R_e – yield point of the billet material, were calculated (Fig. 5).

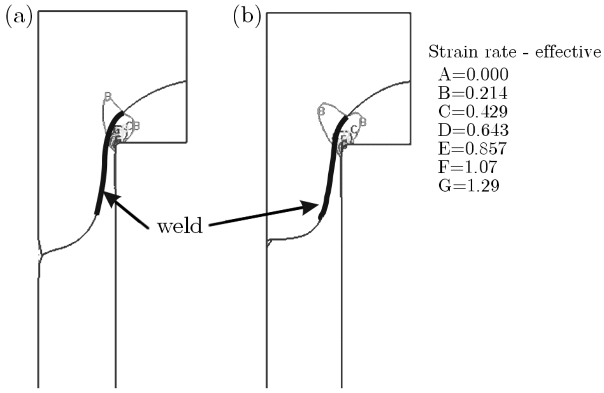

Fig. 4. Strain rates describing the end of weld creation during axisymmetrical forward extrusion through a rectangular die: (a) welding with $m = 0.4$ at the billets interface, (b) welding with $m = 0.9$

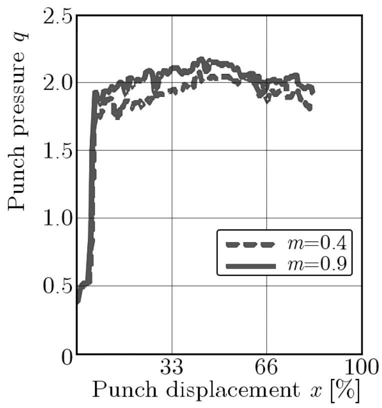

Fig. 5. Punch pressures obtained during forward extrusion through a rectangular die

Using the formula $W = \int P\,dx$, where P is the extrusion force and x – punch displacement, the works of punches for both values of contact friction shear factors were determined and compared. The ratio between the punch work for joining with $m = 0.9 - W_{0.9}$ and $m = 0.4 - W_{0.4}$ was $W_{0.9}/W_{0.4} = 1.08$. This relation reveals that an increase in friction influences the value of the punch work while welding.

Effective strain distributions in the advanced stage of the discussed process (Fig. 6) show the increase in the level of deformation of the top billet in vicinity of the contact line with the increasing contact friction (Figs. 6b and c).

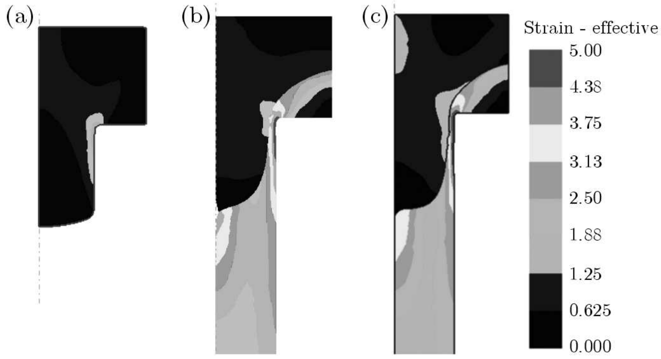

Fig. 6. Effective strain distributions during forward extrusion through a rectangular die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

Velocity distributions show a slide at the contact between the objects in the container dead zone while joining with $m = 0.4$ (Fig. 7b). This phenomenon does not occur for $m = 0.9$ and the flow process is then equal at both sides of the contact line (Fig. 7c).

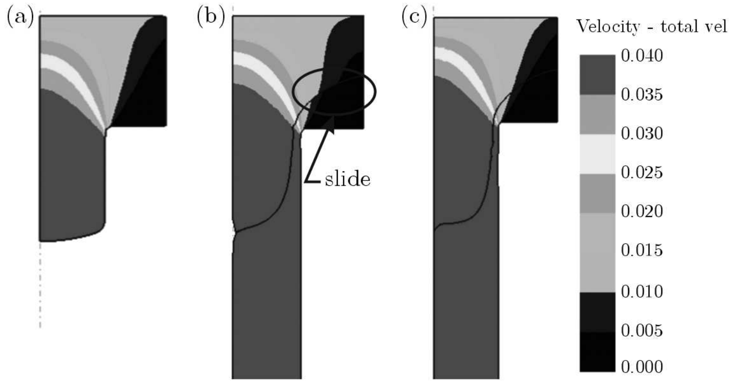

Fig. 7. Velocity distributions while forward extrusion through a rectangular die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

2.3. Welding in the conical die

Joining processes during forward extrusion of cylindrical billets with using a conical die and with different friction factors at the billets interface are shown in Fig. 8. The case with the friction shear factor $m = 0.4$ (Fig. 8b) is characterised by the presence of a significant void between the joined objects, in contrast to the case with $m = 0.9$, where there is a full fill of the contact area (Fig. 8c).

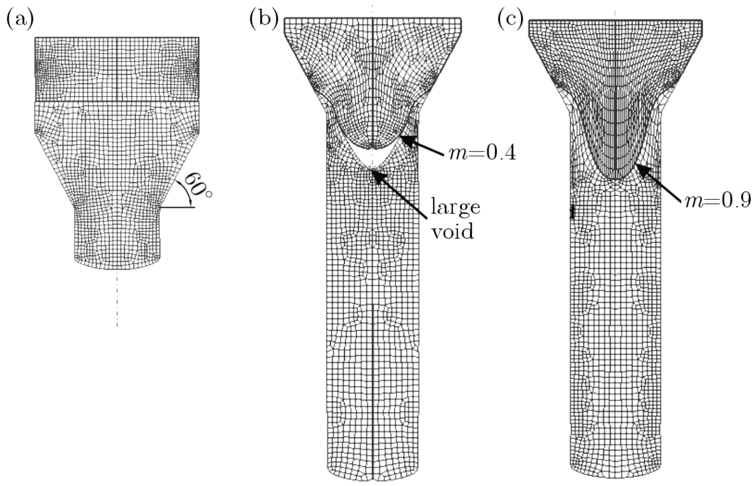

Fig. 8. Joining during forward extrusion through a conical die: (a) view of billets before joining, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

Strain rate images determining the start and finish of the welding processes (Figs. 9 and 10) reveal the significant influence of contact friction on the weld length. A higher contact friction shear factor causes longer joint. However, in both cases the weld seam line is short in relation to the length of the contact line, which eliminates this die profile as a tool for welding while extruding.

Effective strain distributions in the advanced stage of joining with the conical die (Fig. 11) show an increased deformation level of the upper billet with the higher friction factor (Figs. 11b and c). This phenomenon directly influences the size of the welded area in this case.

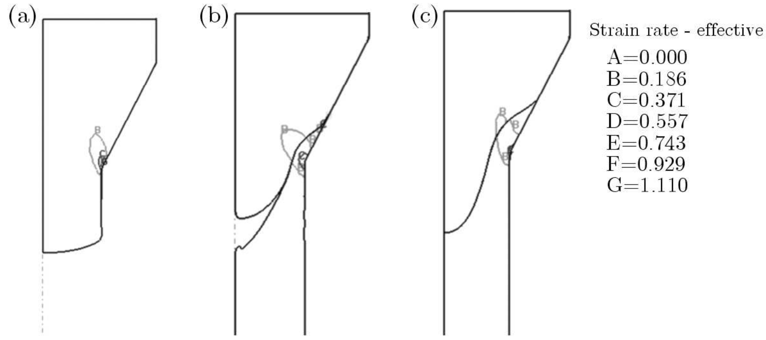

Fig. 9. Strain rates for the beginning of weld creation while forward extrusion through a conical die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

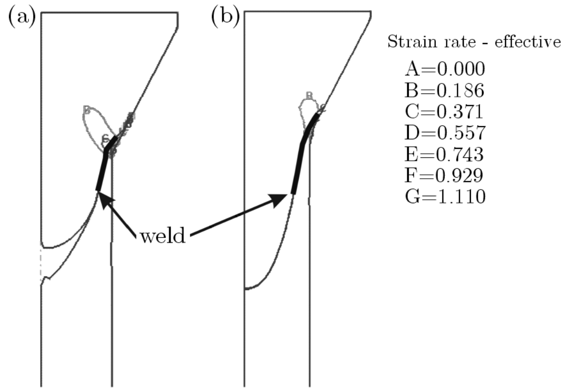

Fig. 10. Strain rates for the end of weld creation while forward extrusion through a conical die: (a) welding with $m = 0.4$ at the billets interface, (b) welding with $m = 0.9$

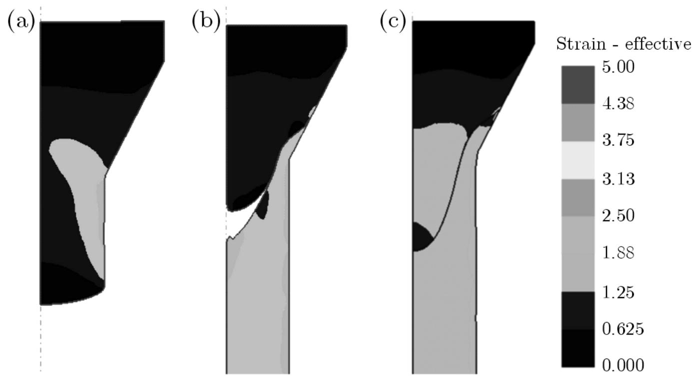

Fig. 11. Effective strain distributions during forward extrusion through a conical die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

Relevant velocity distributions do not show any clear differences in the contour-layout arising from the presence of variable friction shear factors at the billets contact (Fig. 12). The presence of a large void is caused by a slipping present at the initial stage of the billets flow.

2.4. Welding in the rectangular die with the initially formed upper billet

In order to determine the influence of the upper billet spherical face on the welding process, the numerical simulation with the model of a rectangular die was conducted (Fig. 13a). Similarly to the above cases, two values of contact friction shear factors were assumed: $m = 0.4$ and $m = 0.9$. Different friction factors do not influence the billets flow in both analysed processes (Figs. 13b and c). The initially formed upper billet completely filled the contact area in both cases.

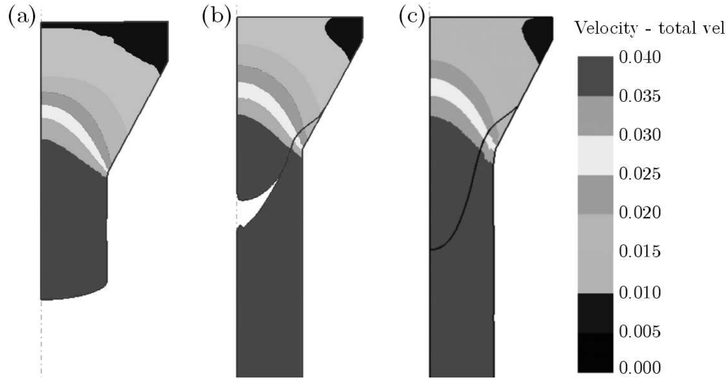

Fig. 12. Velocity distributions during forward extrusion through a conical die: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

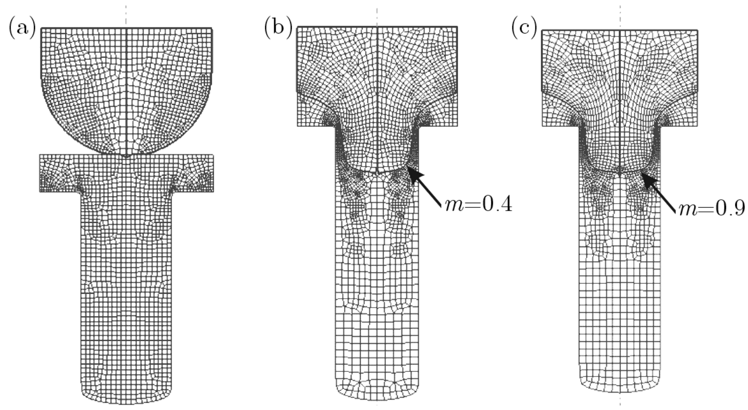

Fig. 13. Joining during forward extrusion through a rectangular die with a spherical face of the upper billet: (a) view of the billets before joining, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

Distributions of the welded billets strain rates appear to be long lines of welds for both analysed friction factors (Figs. 14 and 15). Similarly to joining with conical dies, the increase in contact friction resulted in an increase in the length of the seam weld line (Figs. 15a and b).

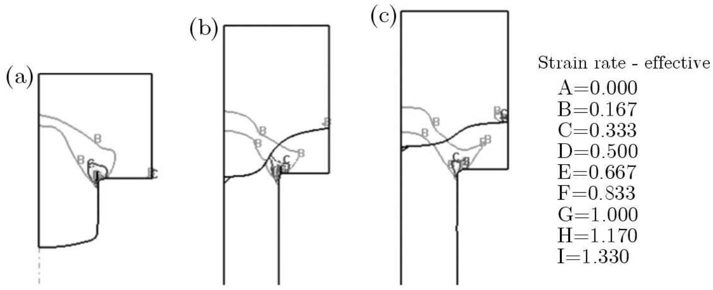

Fig. 14. Strain rates for the beginning of weld creation while forward extrusion through a rectangular die with a spherical face of the upper billet: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

The effective strain images in the advanced stage of the flow process (Fig. 16) show the increase in the deformation degree of the upper billets in the vicinity of the contact lines (Figs. 16b and c). The spherically shaped upper billet face reduced the importance of the friction effect on the stage of deformation along the contact lines.

The velocity distributions show sliding of the objects at the contact line in the container volume while welding with $m = 0.4$ at the interface (Fig. 17b) and equal flow at $m = 0.9$ (Fig. 17c), similarly to the case of the traditional extrusion with the rectangular die.

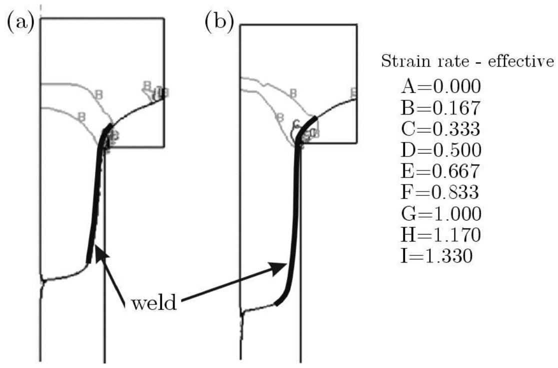

Fig. 15. Strain rates for the end of weld creation while forward extrusion through a rectangular die with a spherical face of upper billet: (a) welding with $m = 0.4$ at the billets interface, (b) welding with $m = 0.9$

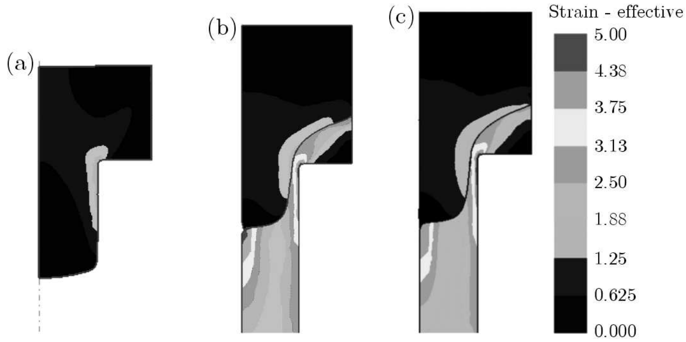

Fig. 16. Effective strain distributions during forward extrusion through a rectangular die with a spherical face of the upper billet: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

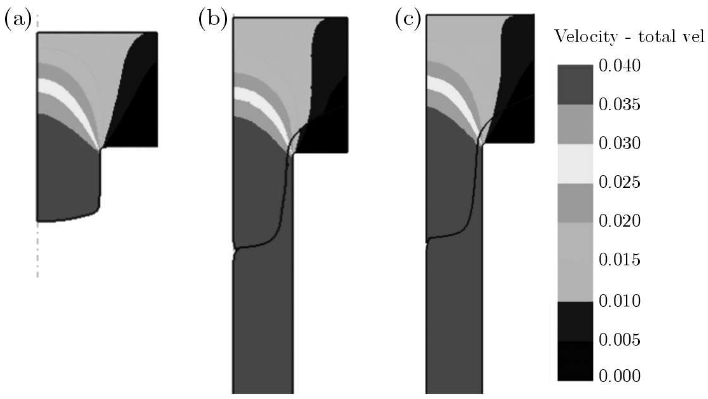

Fig. 17. Velocity distributions during forward extrusion through a rectangular die with a spherical face of the upper billet: (a) extrusion of a single billet, (b) welding with $m = 0.4$ at the billets interface, (c) welding with $m = 0.9$

3. Conclusions

In the paper, the influence of the die profile and face of the upper billet in function of the friction shear factors between the joined billets on the welds lengths obtained during forward extrusion were examined numerically. The concept for determination of the seam weld length at the longitudinal section of joined objects has been presented. This concept postulates that the weld is created when at both sides of the contact line there is homogeneity of strain rate distributions, and they are analogous to the strain rate distribution during extrusion of a single billet with other parameters of welding remained.

Based on the above assumptions, welds lengths at the longitudinal sections of joined elements during extrusion were designated. The influence of the friction shear factor at the billets interface on the size of welded area has been demonstrated. The largest area of the welded surface was obtained while extruding with a rectangular die and a spherically shaped face of the upper billet. The higher the friction factor is the longer weld seam appears at the billet longitudinal-section. In all analyzed cases, lack of the weld presence in the central part of the extruded product has been revealed.

A higher contact shear friction factor at the interface of joined elements during extrusion also affects the increase in the punch pressure and reduces the presence of voids by reducing slides between the objects in the container volume. It increases the level of deformation of the upper billet in the vicinity of the contact line as well.

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