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EXPERIMENTAL STUDY OF V-BENDING PROCESS OF STEEL-POLYMER-STEEL SHEETS AT ROOM TEMPERATURE

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Abstract

The paper is linked to the investigation of formability of three-layer sheets. A sheet consists of two outer layers made of low carbon steel and one polymer inner layer. The polymer's layer lays between the outer layers. The experimental study of V-bending process of composite sheets has been done. The effects of sheet thickness, bending tool geometry and tool speed on flow stress have been investigated. The obtained data were compared with the results of V-bending process of common low carbon steel sheets. It was determined that in case of composite sheets V-bending the effect of tool speed has significant effect on load of deformation and flow stress as well. The possible explanation for the observed effect was given. Data and advices for numerical simulation of the V-bending process are the final output of the paper.

Key words: three-layer sheet, V-bending process, effect of tool speed

1. INTRODUCTION

Multilayer dampen materials, having a view of sandwich-panel (steel – polymer - steel) are widely used in different branches of national economy. The value of these materials is in combination of construction strength properties and absorption capability of vibration and sound vibration. Because of this feature it is not necessary to use extra materials in the construction (Storozhev & Popov, 1977). It makes fitter's work simpler, the weight of construction is decreased, and as a consequence this construction become cheaper.

However, deformation features of these materials are rather different from traditional homogeneous metal sheets. This difference is defined both in deformation and in power aspects (Tipalin et al., 2007, 2008; Hirose et. al., 1990). The objective of the present work is to define material deformation features experimentally when single-angle bending in use and to supply data for numerical simulation of this process.

2. EXPERIMENTAL PROCEDURE

The tests were made on electromechanical uniaxial Zwick/Roell Z-100 machine (Germany). Metal properties determination was made by means of uniaxial sample stretching. Physical properties of samples are as follows: $\sigma_{0.2}$ = 180 N/mm^2, σ_B = 400 N/mm^2, $\sigma = A\,(\varepsilon_0+\varepsilon)^n$, A = 626 N/mm^2; ε_0 = 0.002; n = 0.24). Traverse speed of walking beam is regulated by using electronic control unit. The forces imposed to the sample (100 mm in length and 40 mm in width) were recorded by strain sensor and transformed into electric signal, which was shown at the computer display. Test samples and tools are shown in figure 1. Values of strain rate and punch rounded radius were changing during V-bending process.

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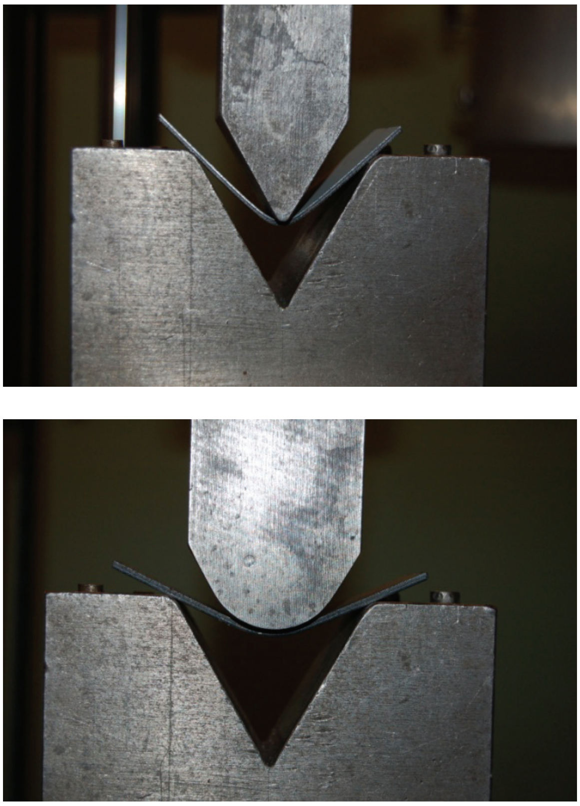

Fig. 1. Experimental V-bending tool set

3. RESULTS

Changes of punch force as a function of the traverse stroke are shown in figure 2. The process parameters were as follows: (1) - punch radius 2.5 mm, traverse speed 10 mm/min, single-layer material; (2) punch radius 2.5 mm, traverse speed 100 mm/min, single-layer material; (3) punch radius 20 mm, traverse speed 10 mm/min, single-layer material. It is seen in this figure that the force does not depend on the process parameters at the first stage of deformation of single-layer material. Different situation is observed in bending of composite sheet with inner polymer layer, see figure 3. The process parameters were as follows: (11) punch radius 2,5 mm, traverse speed 10 mm/min, multilayer material; (12) - punch radius 20 mm, traverse speed 10 mm/min, multilayer material.

As it is shown in figure 4, the influence of the punch radius becomes more important during motion of the tool when relative decrease of bending shoulder takes place due to contact area increase of wrought material. The parameters in this figure are: (8) thickness 2 mm, punch radius 2.5 mm, traverse speed 10 mm/min, multilayer; (10) thickness 2 mm, punch radius 20 mm, traverse speed10 mm/min, multilayer material.

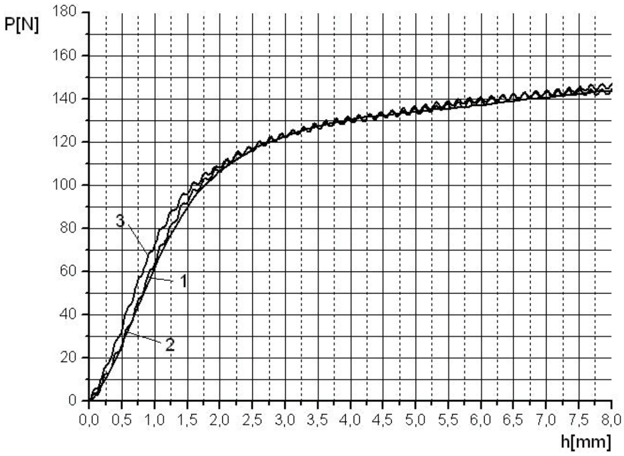

Fig. 2. Punch force as a function of the traverse stroke, single-layer material, thickness1.2 mm.

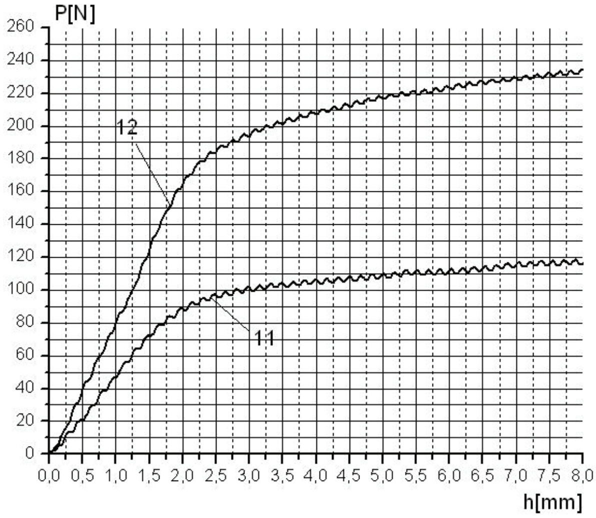

Fig. 3. Punch force as a function of the traverse stroke, multi-layer material, thickness1.2 mm.

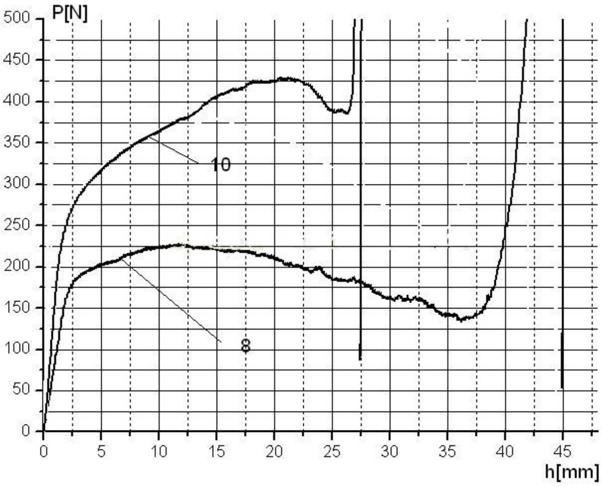

Fig. 4. Dependence of deformation power on tool stroke for various inner radius of the punch.

There is a difference in deformation process when comparing single-layer and multilayer samples. Bending of multilayer sample with one viscoelastic layer requires with lower force than for the single layer sample. Power of deformation depends on traverse speed. Bending force grows with the strain rate increase.

Punch radius has more influence on bending force in multilayer samples, than in single layer one. Analysis of plots of deformation power dependence on traverse stroke (figure 4), shows that the conceptual bending stage (three-point bending) for the single-layer samples does not depend on strain rate and tool radius, as it is seen in figures 5 and 6. Deformation force increases with the rise of sample thickness. This relationship is nonlinear. The parameters in figures 5 and 6 are: (13) punch radius 2.5 mm, traverse speed 10 mm/min, single-layer material; (15) punch radius 20 mm, traverse speed 10 mm/min, single-layer material; (16) punch radius 2.5 mm traverse speed 10 mm/min, multilayer material; (18) punch radius 20 mm, traverse speed 10 mm/min, multilayer material; (5) punch radius 2.5 mm traverse speed 10 mm/min, single-layer material; (6) punch radius 2.5 mm traverse speed 100 mm/min, single-layer material; (7) punch radius 20 mm traverse speed 10 mm/min, single-layer material; (8) punch radius 2,5 mm traverse speed 10 mm/min, multilayer material; (9) punch radius 2.5 mm traverse speed 100 mm/min, multilayer material; (10) punch radius 20 mm, traverse speed 10 mm/min, multilayer material (Tipalin et al., 2007).

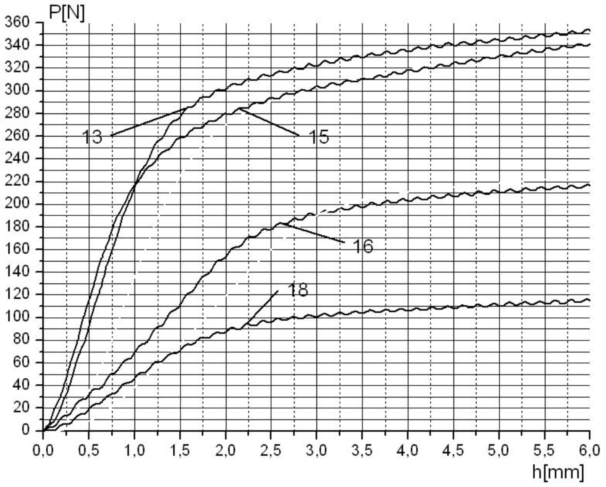

Fig. 5. Punch force as a function of the traverse stroke, thickness 1.5 mm.

The other situation is observed when two-layer steel samples with elastoviscous connecting layer are deformed. In this case an increase of strain rate and bending punch radius leads to decrease of the deformation force. For example, when punch radius increases from 2.5 mm to 20 mm, the bending force is decreased more than 1.5 times. The similar situation takes place in figure 5 when traverse speed increases from 10 to 100 mm/min.

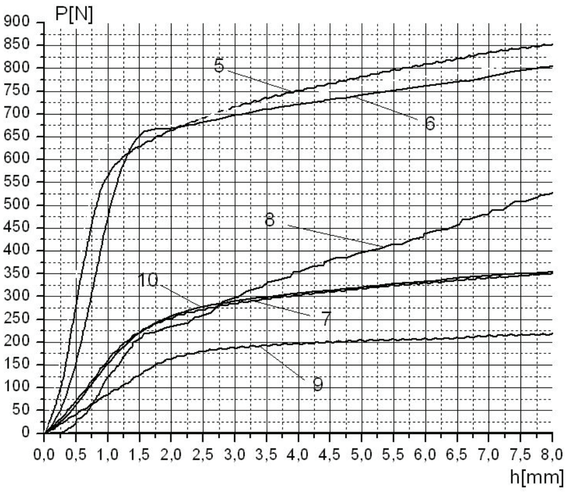

Fig. 6. Punch force as a function of the traverse stroke, thickness 2 mm.

Two phenomena are observed during solid sample bending: outer layer stretching and inner layer compression. In the case of bending of three-layered sample with elastoviscous connecting layer each metal (outer) layer is deformed separately and both mentioned zones occur in both layers. It leads to the decrease of the bending force. However, the tack layer prevents this independent displacement. This leads to the increase of the deformation force in comparison with the other separate samples bending (figure 7).

Comparison of deformation of single-layer and multilayer material of different thickness shows that not only metal properties, but also connecting layer properties have an influence on power characteristics. Thus, to test this phenomenon experiments on multilayer material shift were performed. The samples with cross sow cuts were used for this investigation.

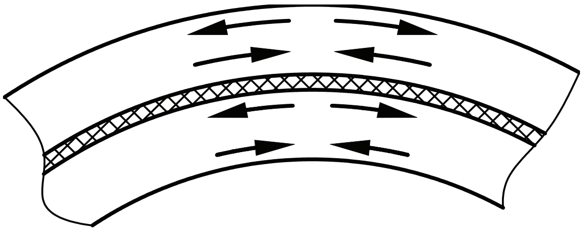

Fig. 7. Multilayer material deformation scheme

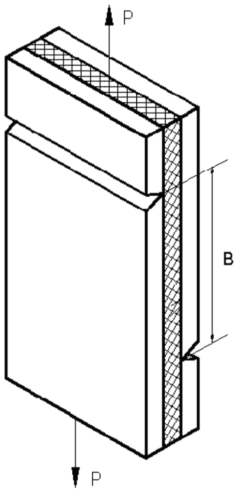

Fig. 8. *Three-layered shear test sample scheme*

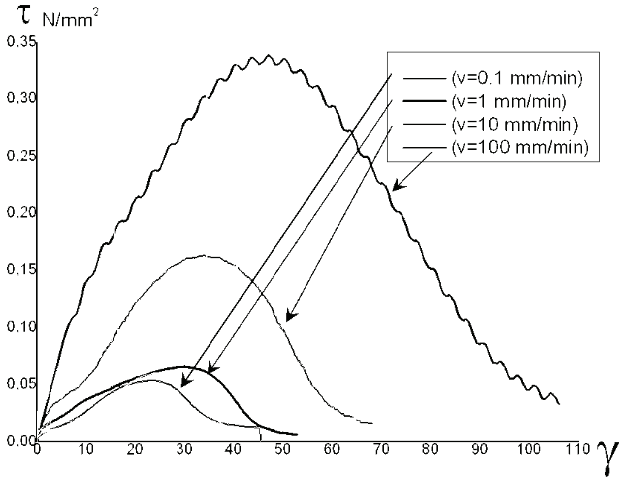

Fig. 9. *Earplug material shear test for various traverse speed.*

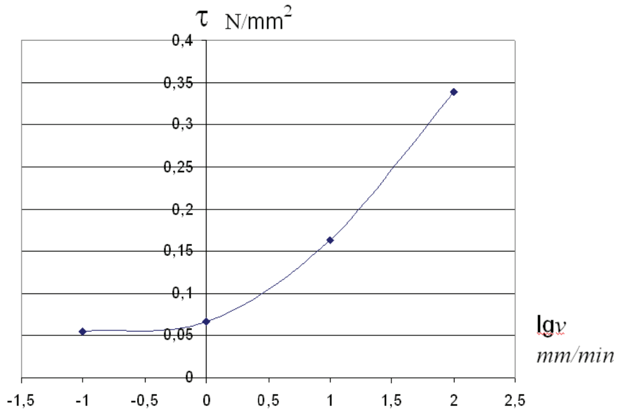

Fig. 10. *Tangential stress dependence on the traverse speed of earplug material elastoviscous layer during shear test.*

During loading process progressive power increase takes place at the beginning of the process and it is followed by the power decrease stage. In the course of experiments force and traverse displacement were measured. Force transformation into stress and displacement into shear deformation were made analytically.

Generalized results of speed influence on shift tangential stress are shown in figure 9. From the diagrams $\tau = f(\gamma)$, shown in figure 9, one can see that the tangential stress drop $\left(\tau = \frac{P}{F}\right)$ occurs near different shift deformation value $\left(\gamma = \frac{\Delta\ell}{z}\right)$. The shear resistance value grows with the increase of the metal layers displacement rate. This is evident from the diagram (figure 9), that shear resistance growth takes place to some defined value. After reaching this value shear resistance stresses starts to decrease. This drop is due to the decrease of adhesion interaction, witch exists as a result of layers defect during the test. This defect is determined by the model of the strain change. To prevent splitting of multi-layer material while shearing it is necessary to provide terms of compression between layers during deformation process. Finally, graphs of the maximal transverse strain dependence on velocity were plotted and are shown in figure 10.

3. DISCUSSION AND CONCLUSIONS

Increase of the layers shear stresses with increasing strain rate (figure 10) explains force parameters modification, arising from multi-layered samples bending in comparison with single-layered one, depending on bending rate and punch radius (figures 1-6). Layers displacement rate is varied during this process.

Recapitulating the presented investigation, the behavior of composite material, i.e. steel-polymer-steel sheet, during bending is different from the bending of common monolithic sheets. The physical and mechanical properties of inner layer influence the flow stress, shear stress and shear strain. Moreover, in comparison with the common sheets the stress and strain analysis in bending process of steel-polymer-steel sheets require to take into consideration the stress and strain of each metallic sheets separately and of the polymer layer, as well.

Tensions, which result from the deformation, are rising nonlinearly during shear rate increase. It has an effect on bending parameters. Relative influence of strain rate increases with decrease of sheet metal thickness during bending process. An increase of the shear strain in connecting due to high strain rate may result in displacement of neutral layer in metal constituents of sample during bending process. It has an affect on the springback of each metal layer and sample as a whole.

Presented tests allow to formulate guidelines for numerical simulation of bending of composite sheets. Numerical analysis of the three-layer sheet bending process should be performed using the following scheme. At the first stage, the material flow during the bending of the uniform metallic sheet non-connected with other layers should be consider. The theoretical analysis of this problem was carried out by many researchers and the results are published in (Matveev, 1983; Moshnin, 1954; Smirnov-Aljaev, 1978; Bondar, 1990).

If the bending is introduced by the bending moment only, the displacement of any point of the bended sheet, the strain rate tensor components, the equivalent strain rate as well as equivalent strain can be determined for any given increment of the bending angle. It should be noted that the change of the bending angle is linked to the curvature of a sheet. During the calculation, it should be taken into consideration that the outer layer is subjected to tension while the inner layer is under the compression. Between these layers, there is the alternating strain region. In this zone, the layers tend to compress till then the neutral layer shifts to the bending center. After that stretching of that layer takes place.

Radial and circumferential stresses components can be determined, using equilibrium equations and Mises yield criterion. Power parameters of the bending process are determined, using integration of the circumferential stresses through the thickness. The change in the location of the neutral layer is defined on the basis of the assumption that the radial stresses on outer and inner interfaces of a sheet are equal to zero. The details of this solution can be found in the reference (Bondar et al., 2003).

The difference between the bending of one-layer sheet and two-layer sheet is that in the latter process the material flow is subjected to the influence of the inner connecting layer. This layer prevents the inner layers of the outer sheet from the compression in circumferential direction and the outer layers of the inner sheet from the stretching in that direction. The retardation of the stretching is constant in terms of its absolute value for each sheet but has the opposite direction.

The presented approach allows to calculate deformation and power parameters of upper and lower layers. The calculation are fulfilled if the velocity field for each material point of the sheet is known for any time during the process and for any given location of the neutral layer. During the deformation the location of the neutral layer changes due to the change in circumferential stresses across the thickness of the sheet and taking into account the radial stresses on the connecting layer.

If the bending of the multilayer sheet is induced by the bending moment only, the normal stresses as well as the radial stresses on upper and lower interfaces of the connecting layer is equal to zero. If the bending of the multilayers sheet is induced by the bending force, the additional circumferential and radial stresses occur in multilayer sheet. In this case, the normal stress in the connecting layer appears. The value of this stress is proportional to the shear force which has the effect on the outer and inner layers of the material. It tends to the appearance of the interfacial radial stresses of the same value but having the opposite directions.

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BADANIA DOŚWIADCZALNE PROCESU ZGINANIA BLACH WARSTWOWYCH STAL-POLIMER-STAL W TEMPERATURZE OTOCZENIA

Streszczenie

Artykuł jest połączony z badaniami odkształcalności kompozytów trójwarstwowych. Blacha składa się z dwóch powłok zewnętrznych wykonanych z niskowęglowej stali oraz jednej wewnętrznej powłoki polimerowej. W ramach niniejszej pracy wykonane zostały badania eksperymentalne zginania trójkątnego takiej blachy kompozytowej. Przegadany został wpływ grubości blachy, kształtu oraz prędkości narzędzia na naprężenie uplastyczniające. Otrzymane wyniki zostały porównane z rezultatami gięcia blach niskowęglowych co, w przypadku stali kompozytowych, pozwoliło na zaobserwowanie znaczącego wpływu prędkości narzędzia na całkowite odkształcenie materiału oraz na naprężenie uplastyczniające. W artykule przedstawiono wyjaśnienie zaobserwowanego zjawiska. Podsumowaniem artykułu są wytyczne dla modelowania numerycznego kompozytów warstwowych stal-polimer-stal.

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