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POSITION OF NEUTRAL AREAS OF INTENSITY OF STRESS AND DEFORMATIONS AT TWO LAYER COMPOSITE MATERIALS

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ABSTRACT

Neutral area of intensity of stress at banding layer composite materials is area on which intensity of stress equals zero. Radial stress at whole section has negative value and maximal intensity on neutral area of stress, and tangential change value from negative to positive or other way around. Neutral area of deformations is area on which fibers are not deformed, and their size before deformation stays the same after deformation. Position of neutral axis at banding two layer composite materials depends on: mechanical characteristics of layer materials, radius of banding, thickness of layers, area of temperature of deformation, speed of deformation and deformation, history of deformation, methods for making two layer composite materials, position of layers in relation to radius of banding or profiling etc. Their positions can successfully be determined by experimentally-analytical methods, on condition that we have modern equipment for preparation, execution and analysis of results of experimentally-analytical researches.

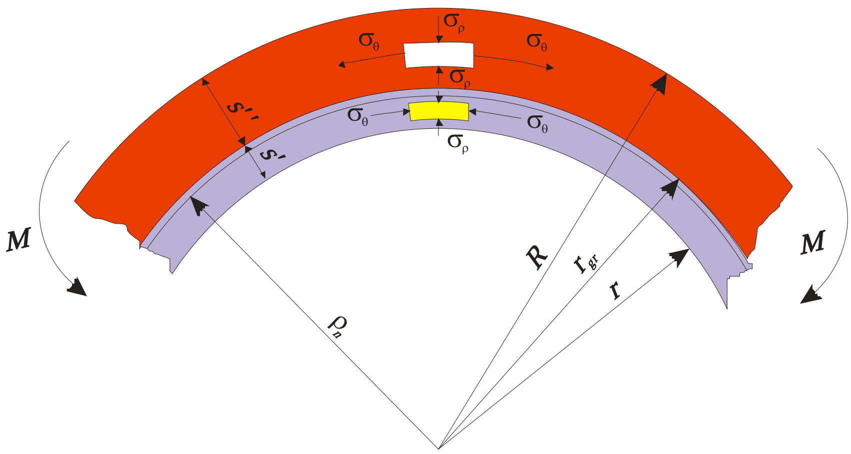
1. INTRODUCTION

At technological operation of banding or profiling, two layer composite materials get to change the curvature of middle area in one plane while at the same time in plane normal on this area of curvature of middle area stays equal to zero or changes minimally. Banding can be made only with moment or transversal force. First case is ideal case of banding because, at that banding, longitudinal or transversal force doesn't exist, that is curvature of middle area is constant in every moment of deformation. Bending is not a monotonous process because neutral areas in every moment change their position in relation to plane of banding. This non-monotonousness is even more expressed at two layer or more layer composite materials, that is if we make banding of more layer composite materials process is getting more complex in relation to banding of one layer.

Constant struggle on market asks for new materials and with them new technology of processing the same materials and all in purpose of quality and economy product. Most researches which are available on market of knowledge are related to banding of one layer materials and to banding of layer composite materials in area of elasticity. Only few researches are studying banding of layer composite materials in elastic-plastic and plastic area. In this research, position of neutral area (neutral lines) of stress of deformation at banding of two layer composite materials is being studied.

2. ANALYSIS OF PROCESS OF BENDING BY MOMENT

Two layer composite materials can be made by several methods, such as: method of hot rolling, explosive welding, pasting, brazing, diffusion act etc. Each of these methods has its advantages and disadvantages but in this research we will not study that problem. At analyzing state of straining at section of two layer composite materials, we'll disregard expanding in direction of third axis. Timetable of stress on section and position of neutral area depends on thickness of layers, mechanical characteristics of layers, radius of banding that is radius of concave and convex area, area of layers in relation to radius of banding. In picture 1. we have geometric values at banding of two layer composite materials and scheme of stress which are on section in area of extension and area of compression.



Picture 1. Geometric values and scheme of stress on section of two layer composite at bending by moment

At banding by moment, distribution of stress on section two of layer composite material can be solved with mutual solving of differential equation of balance and equation of plasticity. Equation of balance in cylindrical coordinates has this form:

$$\rho \frac{d\sigma_{\rho}}{d_{\rho}} + \sigma_{\rho} - \sigma_{\theta} = 0 \qquad (1)$$

where

σ_ρ - normal radial stress

σ_θ - normal tangential stress

and equation of plasticity

$$\sigma_\rho - \sigma_\theta = \pm\beta\sigma_s \qquad (2)$$

Sign plus is related to zone of tension, sign minus for zone of compression, and coefficient is β=1,15 for plain strain condition.
Timetable of stress and deformations on section of profile is in function of position of main layer and cladding layer and radius of banding or profiling. Position of neutral area of stress can be in main layer, cladding layer on border between layers and out of layers.
If we take the case when radius of neutral area of stress is on border between main and layer when the timetable of stress is expressed in next equation:

– for zone of extension

$$\sigma_\rho = -\beta\sigma_s^{''} \ln\frac{R}{\rho}$$

$$\sigma_\theta = -\beta\sigma_s^{''}\left(1 - \ln\frac{R}{\rho}\right) \qquad (2)$$

– for zone of compression

$$\sigma_\rho = -\beta\sigma_s^{'} \ln\frac{\rho}{r}$$

$$\sigma_\theta = -\beta\sigma_s^{'}\left(1 + \ln\frac{\rho}{r}\right)$$

– where:
  – border of yield point for materials of layer on concave side
  – border of yield point for materials of layer convex side
  – radius of convex area
  – radius of concave area and
  – radius of area on which we consider stress.

From condition of continual radial stress on neutral area we get to radius of neutral area of stress on border between layers:

$$\rho_{n\sigma} = \sqrt[1+\frac{\sigma_s^{'}}{\sigma_s^{''}}]{Rr^{\frac{\sigma_s^{'}}{\sigma_s^{''}}}} \qquad (4)$$

With equation (4) we come to conclusion where neutral area of stress, that is neutral line of stress, is located. If obtained radius is bigger than the radius on border between layers, then the neutral area of stress is in the outer layer of two layer composite or if it is smaller, then the neutral area is in inner layer.
If the neutral area is in outer layer of composite, that is radius is bigger than radius on border between layers, than its intensity is in equation:

$$\rho_{n\sigma} = \sqrt{r_{gr} R \left(\frac{r}{r_{gr}} \right)^{\frac{\sigma_s^{'}}{\sigma_s^{''}}}} \tag{5}$$

If neutral area is in inner layer of composite, that is radius is smaller than radius on border between layers, than its intensity is in equation:

$$\rho_{n\sigma} = \sqrt{r_{gr} r \left(\frac{R}{r_{gr}} \right)^{\frac{\sigma_s^{''}}{\sigma_s^{'}}}} \tag{6}$$

From this we can see that the position of neutral area of stress depends on border of beginning of yield material for layers and their positions is related to center of radius of banding. If the neutral area of stress is on border between layers, the equations (5) and (6) become equation (4). If we bend one layer material we can express main form for radius of neutral area of stress for one layer materials

$$\rho_{n\sigma} = \sqrt{rR} \tag{7}$$

All this proves worth for banding without considering reinforcement of materials in process of banding two layers composite.
Intensity of deformation for surface deformation condition:

$$\varphi_i = \frac{2}{\sqrt{3}} \ln \frac{R}{\rho_{n\varphi}}$$, on convex area

$$\varphi_i = \frac{2}{\sqrt{3}} \ln \frac{\rho_{n\varphi}}{r}$$,on concave area

$$\varphi_i = \frac{2}{\sqrt{3}} \ln \frac{r_{gr}}{\rho_{n\varphi}}$$, on border between layers

$$\varphi_i = \frac{2}{\sqrt{3}} \ln \frac{\rho_{n\varphi}}{\rho_{n\sigma}}$$, on neutral layer of stress

While neutral layer of deformation is in form

$$\rho_{n\varphi} = \frac{R^2 - r^2}{2(s'+s'')}$$

where

s' - thickness of layer on concave side and
s'' - thickness on convex side.

2. EXPERIMENTAL RESEARCH

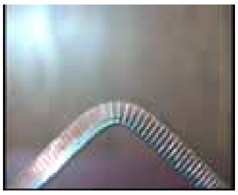
Experimental researches are taken on two layer composite with layer of stainless still and layer of electrolytic copper (C4580-Cu99,9). Geometric values are in table 1. In order to experimentally come to the conclusion regarding the position of neutral line, we have to use the position of neutral line deformation and than with certain correlations come to conclusion where the neutral line of stress is. On inner and outer area of layers, grid of circles of diameter 3mm is made chemically with distance of circles centers 4mm, while on lateral sides of piece parallel lines with distance 1mm are made.

Table 1. Geometry of samples

Characteristics	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*
Position of layer C4580 in relation on radius of banding	*convex side*	*concave side*	*convex side*	*concave side*
Total thickness of section of sample, mm	*4.55*	*4.5*	*4.5*	*4.5*
Thickness of layer Cu99,9	*3.05*	*3.0*	*3.0*	*3.0*
Thickness of layer C4580	*1.5*	*1.5*	*1.5*	*1.5*
Total thickness after deformation of banding	*4.4*	*4.15*	*4.75*	*3.7*
Thickness of layer Cu99,9 after deformation	*3.1*	*2.6*	*3.4*	*2,15*
Thickness of layer C4580 after deformation	*1.3*	*1.55*	*1.35*	*1.55*
Radius punch at banding	*6*	*6*	*2*	*2*
Inner radius on working piece	*11.5*	*6*	*10*	*4*
Outer radius on working piece	*16,1*	*11*	*14,75*	*10.5*
Angle of banding	*81° 10'*	*81° 50'*	*88° 00'*	*84° 10'*
Radius of neutral area of deformation exper. - analytical, mm	*14.7*	*7.59*	*12.96*	*7.37*
Radius of neutral area of stress exper.– analytical, mm	*14.3*	*6.375*	*12.62*	*7*

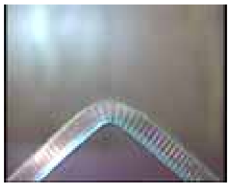
Samples used in experiment are from explosive welding. Picture 2 shows the shape of banded work piece of two layers composite. In them we see positions of layers in relation to radius of banding at banding "V" profiles.

working piece 1



working piece 2

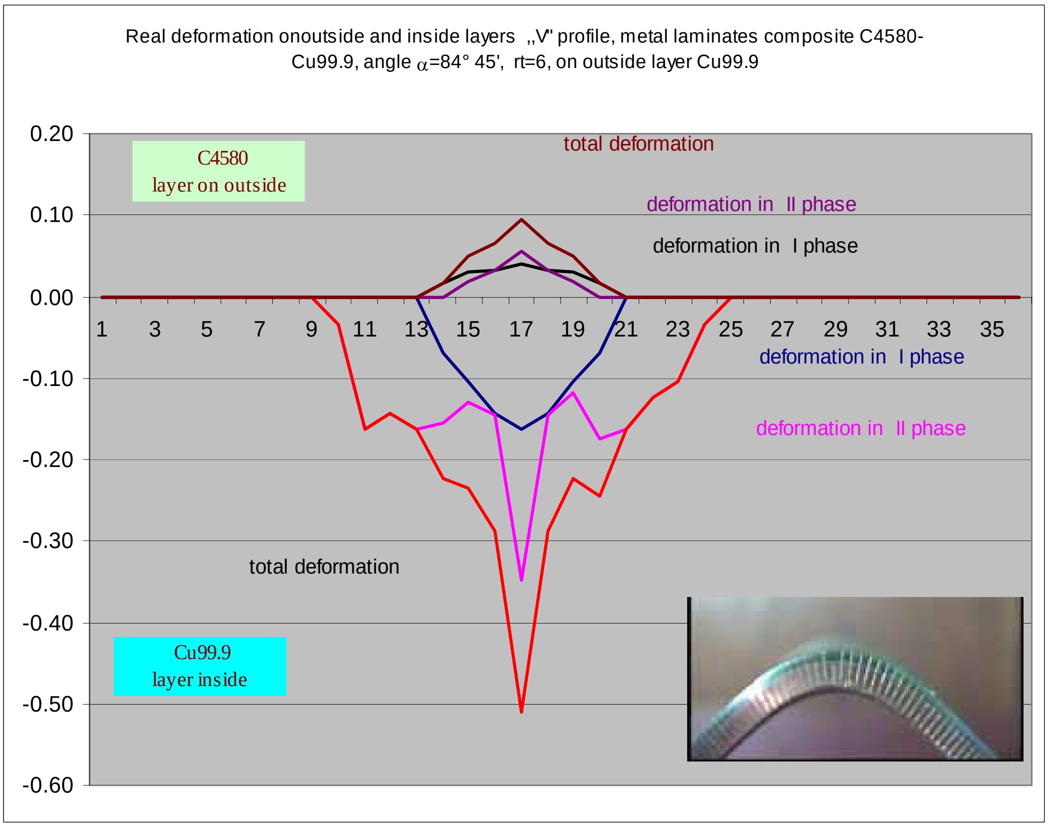
working piece 3



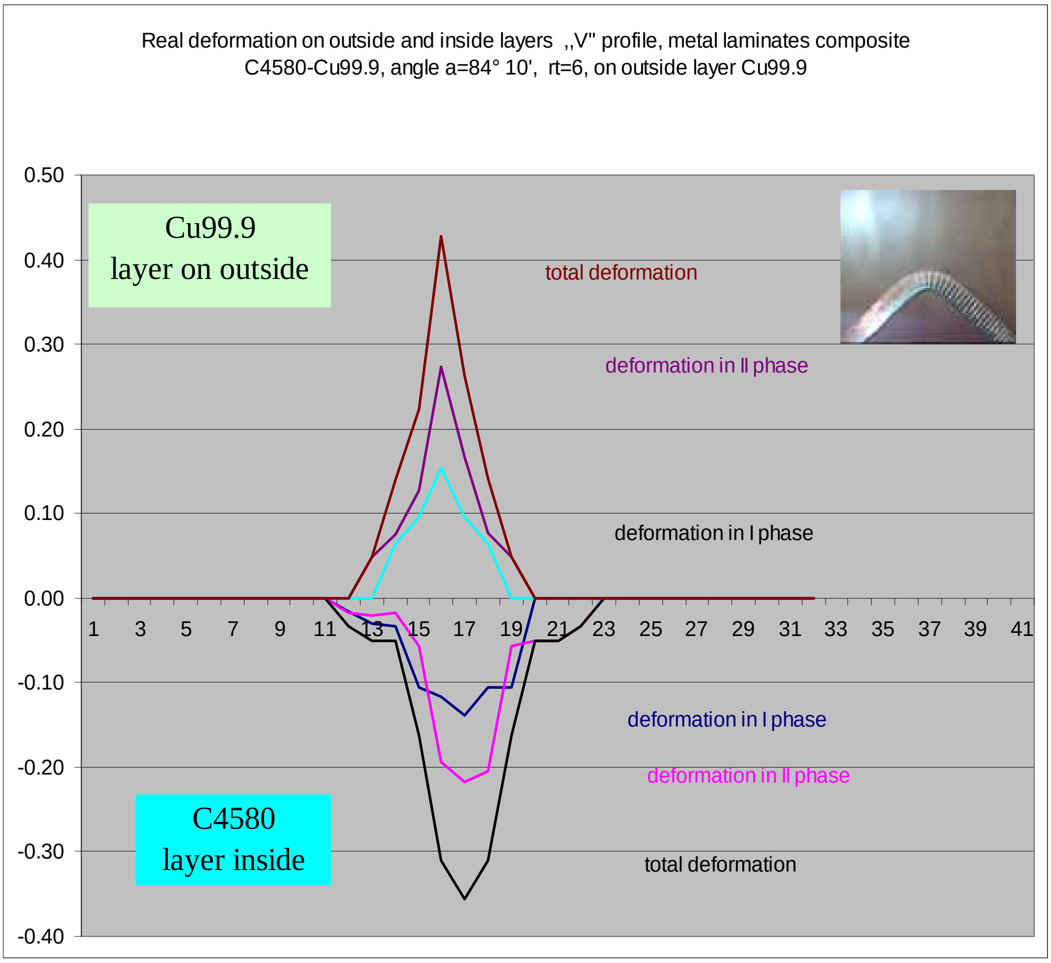
working piece 4

Picture2. Position of layers in relation to radius of banding at two layers composite

By measuring deformations of circles taken on convex and concave area and change of certain known mathematical correlations we get to intensity of deformations in that areas.
Pictures 3. and 4. show intensity of deformations in relation from position of main cladding layer of metal in relation to center of radius of banding.



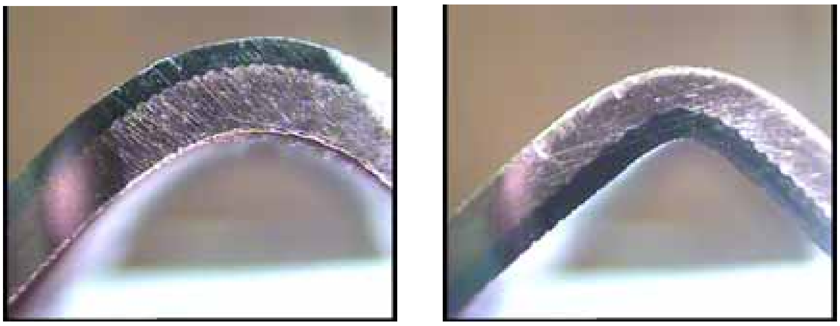
Picture 3. Diagram of intensity of deformations at banding of two layer composite Cu99,9C4580



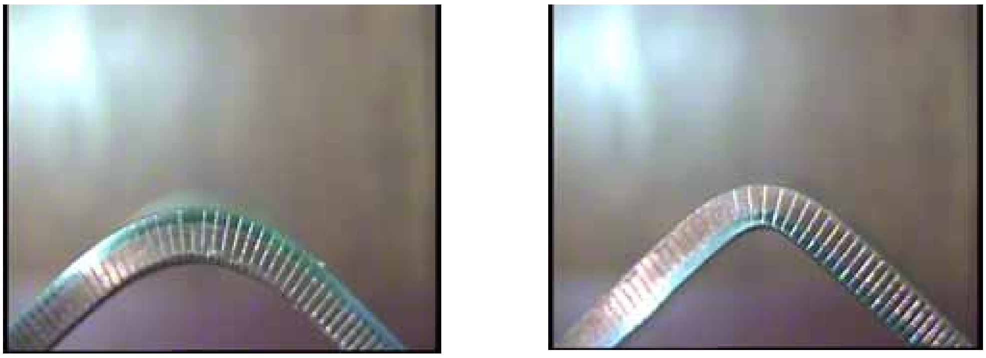
Picture 4. Diagram of intensity of deformations at banding of two layer composite Cu99,9-C4580

3. ANALYZE OF RESULTS

By analyzing intensity of deformations on convex and concave area of working piece we can see that it depends on position of layers in relation to radius of banding, on mechanical characteristics of material of layers, radius of banding, history of deformation. On convex area, when material has higher mechanical abilities for deformation, stress has higher intensity on concave side that is on side of layer than material with lower mechanical abilities. Thinning and thickening of material in deformation area is not expressed. But, radius of deformation are different from radius of tools, that is from wanted radius on working piece. In case when on convex side there is a layer of material with lower mechanical ability, the intensity of deformation on concave and convex side are approaching, but thinning of materials on convex side is prominent, which we can see in picture 5 and 6.



Picture 5. Tapered and increased thickness *of layers of materials at banding of two layer composite C4580-Cu99,9 with radius punch r_t=2mm*



Picture 6. Tapered and increase thickness of layers of materials at banding of two layer composite C4580-Cu99,9 with radius punch r_t=6mm

4. CONCLUSION

Banding is not a monotonous process which is expressed at layer composite.
Position of neutral areas of stress and deformation is in function of:

- mechanical characteristics of layers,
- their position in relation to radius of deformation,
- size of radius of deformation,
- geometrical sizes of layers,
- technology of getting layer composite.

Neutral areas of stress and deformations take positions closer to layer with bigger mechanical abilities. If their position is distanced from border of connection of layers of two layers composite it causes the separation of the layers or local deformations of layers. At banding of two layer composite, as in this research, we can conclude the following: if the layer is with higher mechanical abilities on concave side, then wanted radius of deformation can relative easy be obtained without unwanted deformations: if the layer is on convex side, then obtaining of wanted radius of deformation causes problems which are manifested with extra local negative deformations on concave side, that is it changes the release of concave area which is not allowed. Because of that it is necessary to know which technical characteristics must have layer which is on concave side, and which abilities layer on convex side before making two layers composite. Radius of neutral area of deformation can simply be determined with experimentally-analytical method with condition that geometry on working piece is taken correctly. Radius of neutral areas of stress and deformations are in table 1.

5. REFERENCES

[1] O. Miletic: Constitutive relations of process of continual profiling of composite scale and plate, Monograph of University in Banja Luka, Banja Luka 2002.

[2] O. Miletic: Technology of machine I, University book, Banja Luka 1999.

[3] E.A. Popov: Basics of theory of stamping out of sheet, Masinostroenije, Moscow 1968.

[4] M.Samuel: Experimental and numerical prediction of springback and side wall curl in U-bendings of anisotropic sheet metals, Journal of Material Processing technology, 13 june 2000.

[5] K. Kaw and Gary Willenbring: A Softvare Tool for mechanics of Composite materials, Int. J. Engng Ed. Vol. 13. No. 6, p.433-441, 1997.

POLOŽAJ NEUTRALNE POVRŠINE NAPONA I DEFORMACIJA KOD DVOSLOJNIH KOMPOZITNIH MATERIJALA

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REZIME

Neutralna površina napona kod savijanja slojevitih kompozitnih materijala je površina na kojoj intenzivnost napona jednaka nuli. Radijalni naponi po čitavom presjeku imaju negativnu vrijednost i maksimalni intenzitet na neutralnoj površini napona, a tangencijalni mjenjaju vrijednost od negativne ka pozitivnoj ili obrnuto. Neutralna površina deformacija je površina na kojoj vlakna nisu deformisana tj. njihova veličina prije deformisanja ostaje ista i nakon deformisanja. Položaji neutralnih osa kod savijanja dvoslojnih kompozitnih materijala zavise od: mehaničkih karakteristika slojeva materijala, radijusa savijanja, debljine slojeva, područje temperature deformisanja, brzine deformisanja i deformacije, istorije deformacije, načina izrade dvoslojevitih kompozitnih materijala, položaja slojeva u odnosu na radijus savijanja ili profilisanja itd. Njihovi položaji mogu se uspješno odrediti eksperimentalno-analitičkim metodama uz uslov da raspolažemo sa savremenom opremom za pripremu, izvođenje i analizu rezultata eksperimentalno-analitičkih razmatranja.