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ONE CONTRIBUTION TO THE RESEARCH OF FLOW DIVIDE IN BULK METAL FORMING

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ABSTRACT

One of the main process parameter in bulk metal forming processes is the mode of material flow. In most cases there is simultaneous flow of material particles in different directions. Position of so called "flow divide" within the volume of the workpiece determines the flow mode. Current paper gives insight into the flow divide matter in bulk metal processes with the focus on double backward extrusion
Key words: *bulk metal forming, flow divide, double backward extrusion*

1. INTRODUCTION

In the current development of bulk metal forming processes one of the main efforts is directed towards achievements of high product accuracy. The final goal is to produce ready to install product, which does not need additional machining operations (net shape forming, near net shape forming).
Desired product accuracy can be achieved only if all relevant process parameters and all I elements of working system are designed in optimal way. One of the main parameter is the metal flow during process evolution.
In bulk metal forming operations there is one (or more) plane within the volume of the workpiece in which only axial movement of the workpiece particles takes place, i.e. particles move parallel to the axe of the workpiece. Such a plane divides the volume into two zones with different velocity fields, different strain and stress distribution. It is essential to know the position of such a "flow divide", as it has direct impact on the tool and process design and, subsequently, on quality of the final product.
Flow divide has been analysed by number of authors. In [1] Avitzur developed the method for determination of flow divide in ring compression test. Method is based on differentiation of total energy with respect to neutral radius Rn (Rn – distance from the workpiece axe to the position if flow divide).

Kondo [2] analysed radial extrusion of gears and determined the neutral radius by the equilibrium between resistances of the outward and inward flow. He concluded that in this process the position of flow divide changes during process development. In the initial stage this position is smaller than dedendum circle but in the second stage this position moves outward. In the final stage of radial gear extrusion neutral radius became smaller than dedendum radius. Author showed that such a change of neutral radius has direct impact on the gear quality.

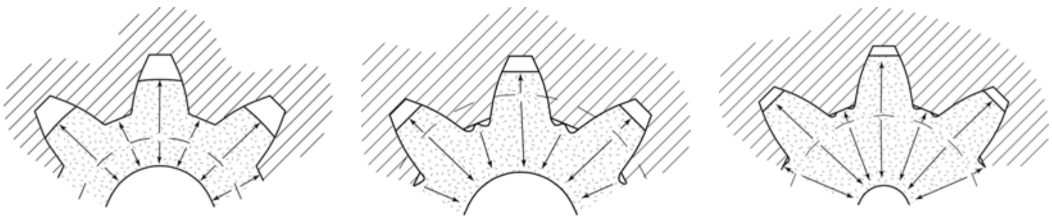


Fig.1. Changes of flow divide during process evolution in radial gear extrusion [2]

Flow divide has been investigated in forging – extrusion [4] and close-die extrusion/forging [5]. In both processes the position of neutral radius has been used for a subsequent upper bound analysis.

The present work describes ongoing investigations on neutral radius in bulk metal forming operations. Possibilities for determination of this radius are analysed. Theoretical and experimental investigation of flow divide in inverted double backward extrusion has been presented. Slab method was applied to determine the position of neutral radius. Theoretical results had been checked by experiments.

2. POSSIBILITIES FOR THE DETERMINATION OF NEUTRAL RADIUS

There exist different theoretical and experimental methods for the determination of neutral radius in bulk metal forming operations.

As mentioned above, Avitzur applied Upper Bound Method to obtain total energy in the process of ring compression. The value of R_n is found by differentiating of total energy J with respect to R_n:

$$J = \frac{2}{\sqrt{3}}\sigma_0 \int_V \sqrt{\frac{1}{2}\dot{\varepsilon}_{ij}\cdot\dot{\varepsilon}_{ij}}\,dV + \int_S \tau\left|\Delta v\right| dS - \int_S \sigma_i \cdot v_i \, dS$$

$$\frac{dJ}{dR_n} = 0 \tag{1}$$

Slab Method was applied for determination of neutral radius in inverted double backward extrusion [3], Fig.2. Total volume of the workpiece was divided into 3 zones and every zone has been analysed by Slab method, using appropriate boundary conditions.

The zone II was divided into 2 sub-zones (IIa and IIb). As a result of the analysis of zone II (IIa and IIb) normal pressure distribution at the punch head has been established for both sub-zones. Neutral radius has been then determined by equating obtained normal pressure in two sub-zones:

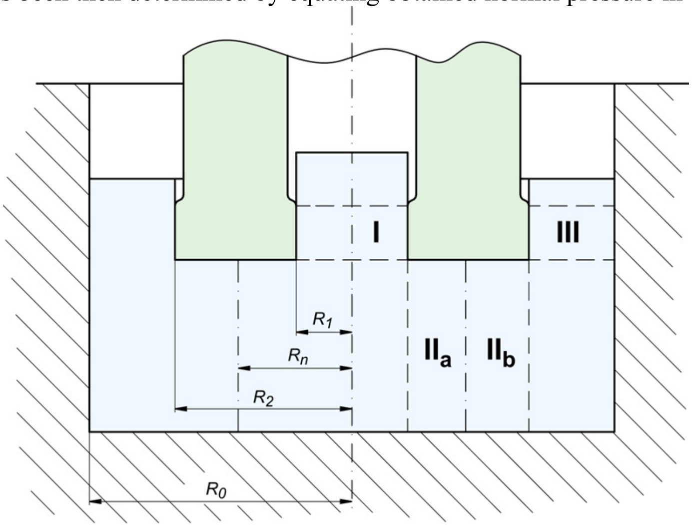


Fig.2. Inverted double backward extrusion

$$\sigma_{n_{2a}} = k\left(1+\frac{2\cdot\mu}{h}\left(r-R_1\right)\right)+k\cdot e^{\frac{2\cdot\mu R_n^2}{R_1^3}s}$$

$$\sigma_{n_{2b}} = k\left(1+\frac{2\cdot\mu}{h}\left(R_2-r\right)\right)+k\cdot e^{\frac{2\cdot\mu\left(R_o^2-R_n^2\right)}{\left(R_o-R_2\right)\left(R_o^2-R_2^2\right)}s}$$

$$\sigma_{n_{2a}} = \sigma_{n_{2b}}\Big|_{r=R_n} \qquad (2)$$

Following equation has been obtained for the neutral radius:

$$a\cdot R_n^4+b\cdot R_n^2+c\cdot R_n+d=0 \qquad (3)$$

$$a=\mu\cdot s^2\left(\frac{1}{R_1^6}-\frac{1}{(R_o-R_2)^2(R_o^2-R_2^2)^2}\right)$$

$$b=s\left(\frac{1}{R_1^3}+\frac{1}{(R_o-R_2)(R_o^2-R_2^2)}\left(1+\frac{2\cdot\mu\cdot s\cdot R_o^2}{(R_o-R_2)(R_o^2-R_2^2)}\right)\right)$$

$$c=\frac{2}{h}$$

$$d=-\left(\frac{R_1+R_2}{h}+\frac{s\cdot R_o^2}{(R_o-R_2)(R_o^2-R_2^2)}\left(1+\frac{\mu\cdot s\cdot R_o^2}{(R_o-R_2)(R_o^2-R_2^2)}\right)\right)$$

Coefficients a,b,c and d are constant for given geometry and given friction. Determination of Rn from (3) has been carried out numerically.

Knowing "R_n" extrusion force can be obtained as follows:

$$F = \int_{R_1}^{R_n} \sigma_{n_{2a}} \cdot 2\pi \cdot r \cdot dr + \int_{R_n}^{R_2} \sigma_{n_{2b}} \cdot 2\pi \cdot r \cdot dr$$

$$F = k \cdot \pi \left[\left(1 - \frac{2 \cdot \mu}{h} R_1 + e^{\left(\frac{2 \cdot \mu \cdot R_n^2}{R_1^3} s \right)} \right) \left(R_n^2 - R_1^2 \right) + \frac{4 \cdot \mu}{3h} \left(R_n^3 - R_1^3 \right) + \right.$$
$$\left. + \left(1 + \frac{2\mu \cdot R_2}{h} + e^{\left(\frac{2 \cdot \mu \left(R_o^2 - R_n^2 \right)}{(R_o - R_2)\left(R_o^2 - R_2^2 \right)} s \right)} \right) \left(R_2^2 - R_n^2 \right) - \frac{4 \cdot \mu}{3h} \left(R_2^3 - R_n^3 \right) \right] \tag{4}$$

Experimental determination of flow divide is based upon the principle of volume equilibrium. Volume of workpiece which is displaced by the downward stroke of the punch is equal to the volume which flows right and left of the neutral radius [5].

In Table 1. some examples of the experimental determination of neutral radius Rn by the method of volume equilibrium are given.

Above table comprises:

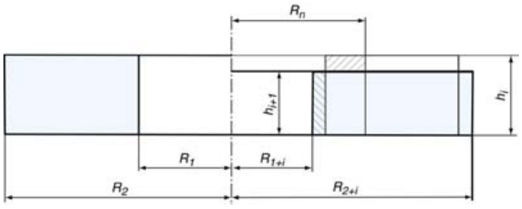
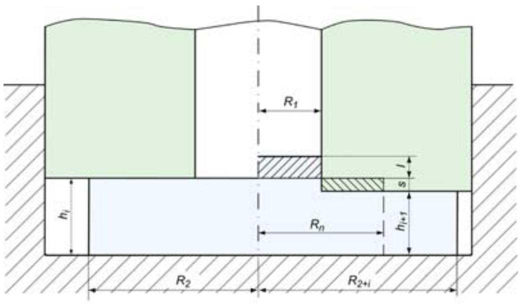
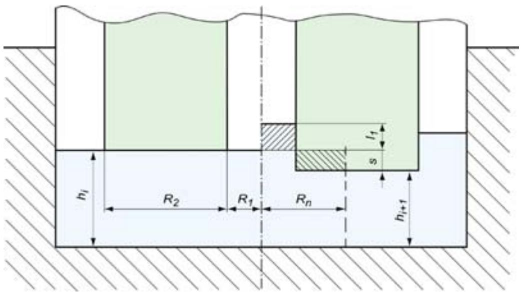
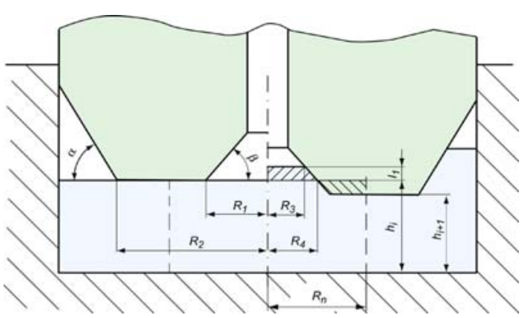
- the scheme of the process with the indicated position of neutral radius R_n
- the scheme explaining the volume equilibrium approach (in all examples radius R_n can be determined by considering either a) outward or b.) inward flow). In the Table 1. inward flow was considered.
- expressions for the neutral radius

All what is needed by this approach is to measure relevant geometrical parameters, substitute them into the appropriate equation (Table 1) and calculate neutral radius.

3. NEUTRAL RADIUS IN INVERTED DOUBLE BACKWARD EXTRUSION

Theoretical and experimental investigations have been conducted into the problem of neutral radius in the process of inverted double backward extrusion, in order to determine the impact of different parameters on the flow divide. As the theoretical analysis has been presented elsewhere [3], [6], it will be omitted here. Only final theoretical results will be considered and compared to experimental results.

Table 1.

	$\left(R_n^2 - R_1^2\right)\pi\left(h_i - h_{i+1}\right) = \left(R_1^2 - R_{1+i}^2\right)\pi \cdot h_{i+1}$ $R_n = \sqrt{R_1^2 + \left(R_1^2 - R_{1+i}^2\right)\dfrac{h_{i+1}}{\left(h_i - h_{i+1}\right)}}$
	$\left(R_n^2 - R_1^2\right)\pi \cdot s = R_1^2 \cdot \pi \cdot l$ $s = h_i - h_{i+1}$ $R_n = \sqrt{R_1^2 + R_1^2 \dfrac{l}{h_i - h_{i+1}}}$
	$\left(R_n^2 - R_1^2\right)\pi \cdot s = R_1^2 \cdot \pi \cdot l_1$ $s = h_i - h_{i+1}$ $R_n = \sqrt{R_1^2 + R_1^2 \dfrac{l_1}{h_i - h_{i+1}}}$
	$R_n^2 \cdot \pi \cdot s - \dfrac{s \cdot \pi}{3}\left(R_1^2 + R_1 R_4 + R_4^2\right) =$ $\dfrac{l_1 \cdot \pi}{3}\left(R_4^2 + R_4 R_3 + R_3^2\right)$ $s = h_i - h_{i+1}$ $R_n = \sqrt{\dfrac{R_1^2 + R_1 R_4 + R_4^2}{3} + \dfrac{l_1}{3 \cdot \left(h_i - h_{i+1}\right)}\left(R_4^2 + R_4 R_3 + R_3^2\right)}$

For the experimental investigation AlMg2 billets with the dimensions of Φ 28 x 25 mm were used. The stress-strain curve has the analytical form $k = 280\varphi^{0.166}$. No lubrication was applied. The lay out of the experimental tooling is shown in Fig.3.

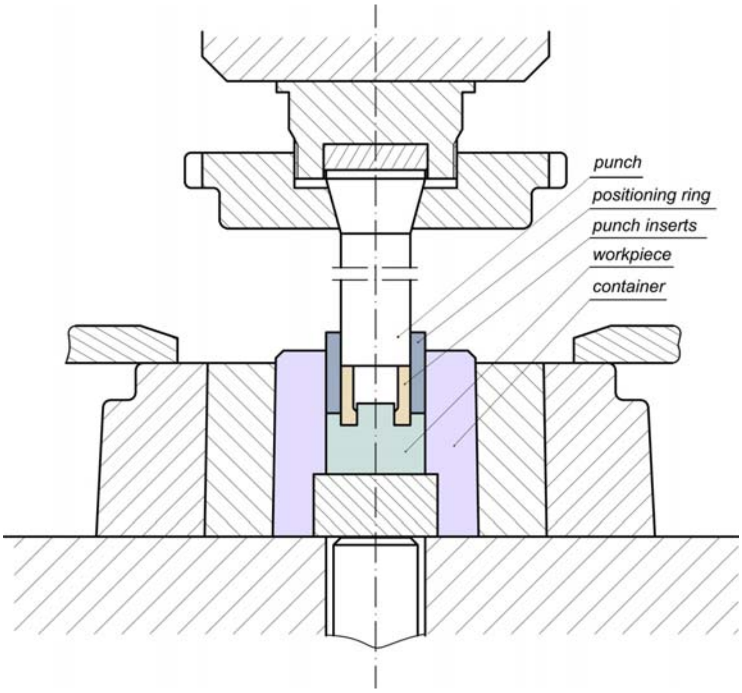


Fig.3. General lay-out of the experimental tooling

Three different punch geometries have been used. This was realised by applying of replaceable inserts at the punch head. In Fig.4. punch, punch inserts and workpieces are shown.

Fig.4. Punch, punch inserts and workpieces

In Fig.5 theoretical curve R_n – R_2/R_0 is shown (for the nomenclature, see fig.2). As it can be seen, neutral radius moves outward as inner punch hole becomes relative larger, compared to the wall thickness.

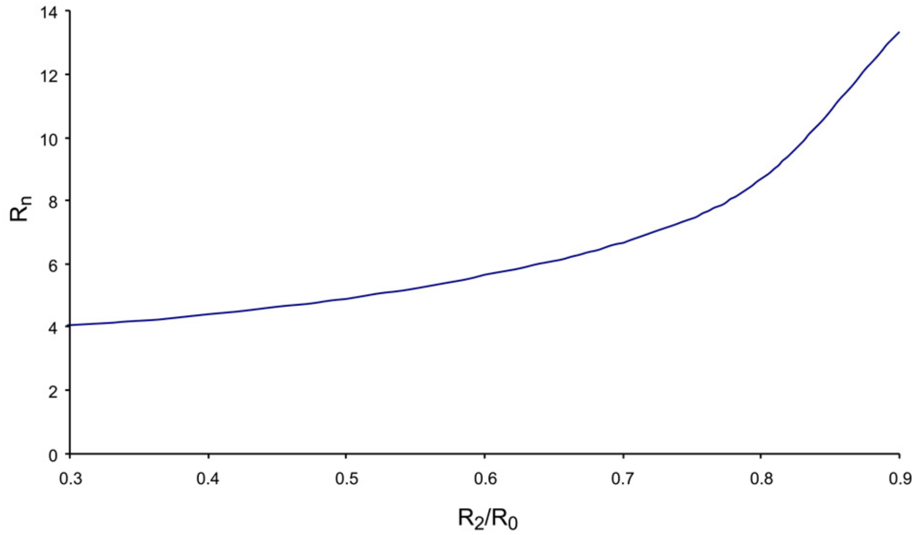


Fig.5. Curve R_n – R_2/R_0
(R_1=5mm, R_0=20mm, H_o=25mm, μ=0.15, s=3mm)

Theoretical results show that there is only slight influence of initial height of the workpiece on the position of neutral radius (Fig.6).

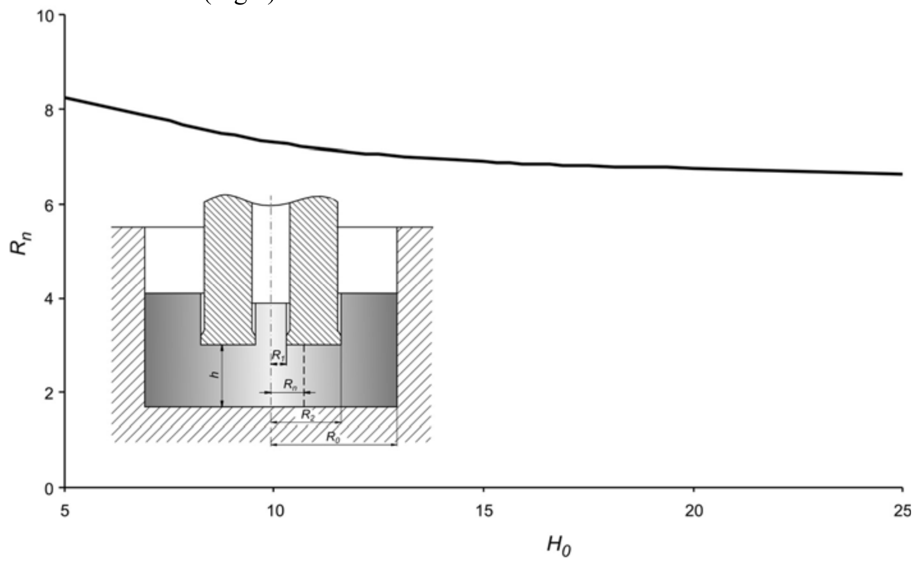


Fig.6. Influence of initial height of the workpiece on the position of neutral radius
(R_1=5mm, R_2=14mm, R_0=20mm, s=3mm, μ=0.15)

Dependence of forming load on punch geometry Fig.7.

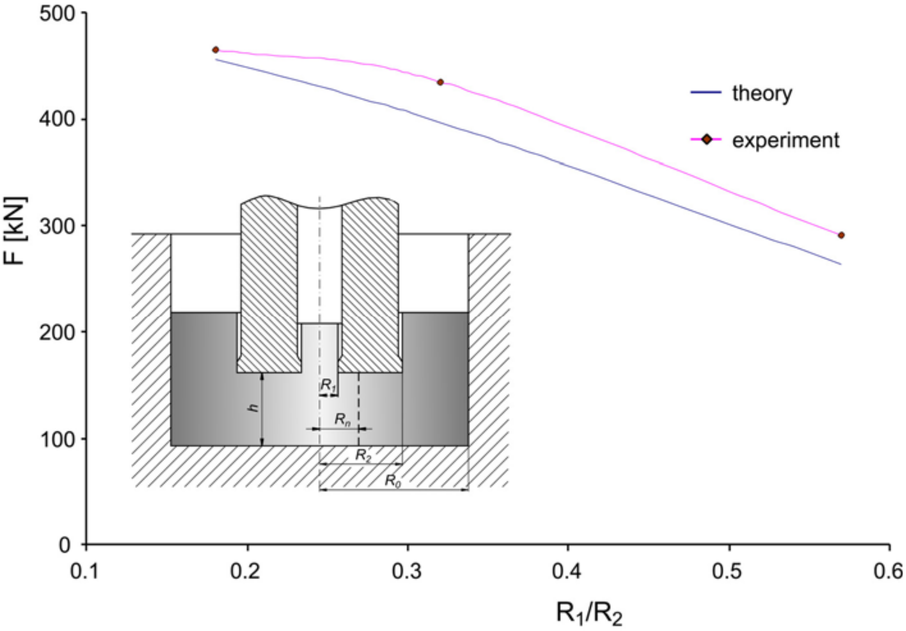


Fig.7. Dependence of forming load on punch geometry
(R_2=14mm, R_0=20mm, H_o=25mm, s=3mm, μ=0.15)

Diagram indicates very good agreement between theoretical and experimental results.
In Fig.8. theoretical and experimental relationship $R_n - R_1/R_2$ is shown.

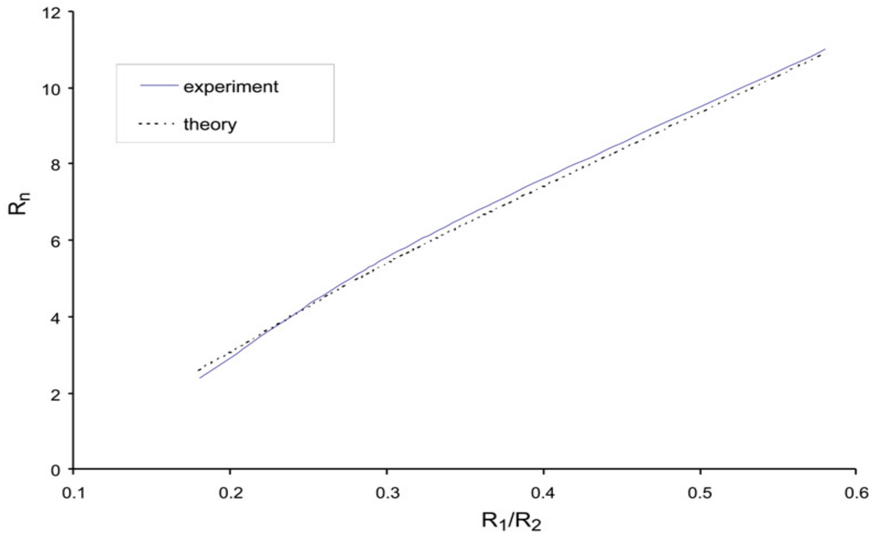


Fig.8. Theoretical and experimental relationship $R_n - R_1/R_2$
(R_2=14mm, R_0=20mm, H_o=25mm, s=3mm, μ=0.15)

4. CONCLUDING REMARKS

One of the most important direction of research and application of cold bulk metal forming is Net-shape and Near-Net-Shape forming. These are technologies which make possible to manufacture ready-to-install components or, at least, components which requires minor additional operations before being assembled. Through application of above mentioned technologies essential labour-, recourses and energy saving could be achieved.

Realization of Net-Shape forming requires a knowledge and control of all relevant process parameter during process evaluation. One of the most important and most influential parameter is material flow. Extrusion of complex shapes involves simultaneous flow of material particles in different directions. In this way different zones within the workpiece volume occur. These zones are divided by "flow divide". Determination of flow divide is possible by experiment and theoretically.

This paper presents the possibilities of determination of flow divide (neutral radius) in some typical bulk metal forming operations. Furthermore, process of double backward extrusion has been analysed (theoretically and experimentally) from the point of view of neutral radius. It has been concluded that R_n changes during deformation. Position of this radius , in dependence of process geometry, has been determined. Impact of billet initial height and punch geometry (relation between inner and outer punch diameter) on the position of flow divide has been analysed.

5. LITERATURE

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PRILOG ISTRAŽIVANJU TEČENJA MATERIJALA U PROCESIMA ZAPREMINSKOG DEFORMISANJA

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Delove dobijene hladnim zapreminskim deformisanjem karakteriše visoka tačnost izrađenih delova i poboljšana mehanička svojstva.

Zahtevana tačnost obratka može biti ostvarena jedino ako su svi relevantni parametri procesa i svi elementi obradnog sistema projektovani na optimalan način. Jedan od osnovnih parametara je tečenje materijala tokom izvođenja procesa. Priroda tečenja u mnogome zavisi od položaja tzv. neutralnog radijusa R_n. *To je radijus koji deli zapreminu materijala obratka na dva dela i određuje količinu istisnutog materijala sa svake strane žiga.*

U ovom radu je data teorijsko-eksperimentalna analiza procesa dvostrukog suprotnosmernog istiskivanja koji reprezentuje nekoliko geometrijski sličnih procesa. Teorijska analiza je izvršena metodom tankih preseka. Ovaj proces karakteriše višesmerno tečenje materijala gde intenzitet tečenja u određenim smerovima zavisi od geometrije alata.

Za potrebe eksperimenta je razvijena specijalna konstrukcija alata sa izmenjivim umetcima koji reprezentuju različite geometrije žiga. Eksperiment je izveden na Fakultetu tehničkih nauka u Novom Sadu u laboratoriji za obradu deformisanjem na presi Sack&Kiesselbach nominalne sile 6.3MN.

Za eksperimentalna istraživanja je korišćena legura aluminijuma AlMg2 ($k = 280\varphi^{0.166}$*). Eksperiment je izvođen za tri različite geometrije alata i upoređivane su dobijene teorijske vrednosti položaja neutralnog radijusa sa vrednostima dobijenim eksperimentom.*

Ovaj rad daje mogućnost teoretskog određivanja položaja neutralnog radijusa za tipičan proces zapreminskog deformisanja.