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NON-STATIONARY OF THE DEEP DRAWING PROCESS

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ABSTRACT
In this work the dependency of the ring flange radius and the cylindrical cup depth will be shown, such as the interdependancy of the external radius ring and inner ring of the cylindrical cup per phase. After the model's deducing of the relative strain degrees of the external and inner ring of the cup with flange and the calculation of their values, diagrams will be drawn on which it can be seen that they are not mutually equal during the process. That is going to show that in the case of the first operation the process of deep drawing is non- stationary.
Keywords: deep drawing, non-stationary, blank, cup with flange, radius ring, relative strain degree

1. INTRODUCTION
For the analysis of the strains, the deep drawing process of a cylindrical cup will be shown in just one operation, but through three phases which are followed one after another in continuity. In that Figure 1. is a cup of actual dimension shown, in which it can be seen that it starts from the initial blank diameter $D_0=75$ mm and its thickness s =1 mm, and at the end of the process the inner diameter of the finished cup needs to be $d_1=40$ mm and the depth $h_1=25$ mm.
On the one hand, the proceeding of the process can be observed through of reducing the external ring of the flange diameter with the increasing of the cup's depth. On the other hand, the phases of deep drawing can be observed as they are following one after another i.e. at the end of one phase another is added. However, it is also a good idea to observe every phase independently of the one before knowing that some inter phase has just been incidental to another actual phase. In case of observing the second phase, it is known that the first phase happened, but only as an incidental one because the second phase can be viewed not only as the one after the first phase but also from the beginning of the process as the first phase did not happen.
Having in mind what has been said above, looking e.g. on the first phase, two circular blank rings on the flange can be noticed, one external and one inner ring. To the external ring is the external flange rim attached, and it is at first the circular rim of the blank and that rim travels to the cup's center. So, that rim begins from the radius blank of R_0=37,5 mm and ends at the radius of R'_x =31,7 mm. That part of the flange in this phase has not still arrived in the die, but therefore is another part of the flange inner circular ring which completely enters into the die formating the wall of that phase.
So, it is about the inside part of the flange which external radius is r'_x=28,4 mm and results in the radius r_1=20 mm, exactly how the wall radius of the cup is because it is in fact almost the punch radius which is constant through all phases. Now, what is going to be observed are the external circle rims of the external and inside part of the flange and the strain of those circles at their travel towards the centre of the cup because then they are reducing. The external flange rim is the one which begins with the blank of R_0=37,5 mm and it is always visible. But the inner flange rim is not visible, it is not marked with anything (although it can be drawn) and it begins with the radius r'_x=28,4 mm. It is easy to conclude that the external and inner circular flange ring and the wall have the same surface (i.e. volume) in the first phase (as in some later phase) and that the bottom of the cup has no influence on it.

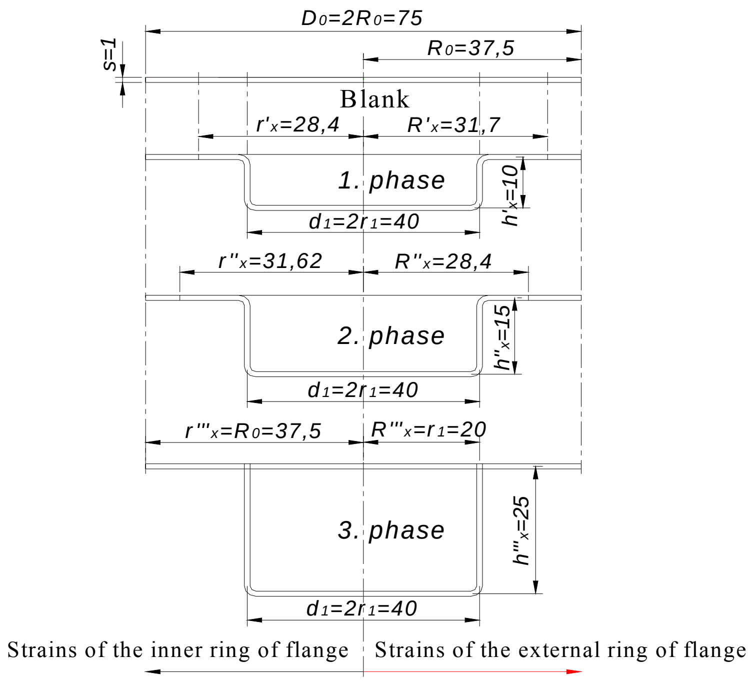

Figure 1. Cylindrical cup strains through the phases [1]

2. DEPTHS, RADII AND RELATIVE STRAIN DEGREES OF THE CUP WITH FLANGE PER PHASES

Finally, from the equivalence of the volume (surface) of the wall and external ring flange in the first phase is:

$$2\cdot\pi\cdot r_1\cdot h'_x\cdot s=\left(R_0^2-R_x'^2\right)\cdot\pi\cdot s\Rightarrow h'_x=\frac{R_0^2-R_x'^2}{2\cdot r_1}=\frac{D_0^2-D_x'^2}{4\cdot d_1}\ ,\ \text{i.e.}$$

$$R'_x=\sqrt{R_0^2-2\cdot r_1\cdot h'_x}\ . \qquad (1)$$

Same as that, from the equivalence of the volume of that same wall and inner ring flange in first phase is :

$$2\cdot\pi\cdot r_1\cdot h'_x\cdot s=\left(r_x'^2-r_1^2\right)\cdot\pi\cdot s\Rightarrow h'_x=\frac{r_x'^2-r_1^2}{2\cdot r_1}=\frac{d_x'^2-d_1^2}{4\cdot d_1}\ ,\ \text{i.e.}$$

$$r'_x=\sqrt{r_1^2+2\cdot r_1\cdot h'_x}\ . \qquad (2)$$

On the basis of these forms and the implied drawing per phases h'_x, h''_x, h'''_x, the cup flange radii per phases R'_x, R''_x, R'''_x i.e. r'_x, r''_x, r'''_x can be calculated.

Now, the relative linear strain degree ε can be calculated per phase, specially for the external ε_R and specially for inner flange rims ε_r knowing that the degree is got as the quotient amount of the decreased circumference of the external circle and its beginning circumference i.e. quotient amount of the reduced inner circle and its beginning circumference:

$$\varepsilon'_R=\frac{2\cdot R_0\cdot\pi-2\cdot R'_x\cdot\pi}{2\cdot R_0\cdot\pi}=\frac{R_0-R'_x}{R_0}\ ,\ \text{so it is finally :}\quad \varepsilon'_R=1-\frac{R'_x}{R_0}\ , \qquad (3)$$

$$\varepsilon'_r=\frac{2\cdot r'_x\cdot\pi-2\cdot r_1\cdot\pi}{2\cdot r'_x\cdot\pi}=\frac{r'_x-r_1}{r'_x}\ ,\ \text{so it is finally :}\quad \varepsilon'_r=1-\frac{r_1}{r'_x}\ . \qquad (4)$$

Also form the volume (surface) equivalence of the external and inner cup flange ring (first phase) direct relations can be set between the variable radii R'_x and r'_x , also phase :

$(R_0^2 - R_x'^2)\cdot\pi\cdot s = \left(r_x'^2 - r_1^2\right)\cdot\pi\cdot s$, follows directly :

$$R'_x = \sqrt{R_0^2 + r_1^2 - r_x'^2}\ , \qquad (5) \qquad \text{i.e.} \qquad r'_x = \sqrt{R_0^2 + r_1^2 - R_x'^2}\ . \qquad (6)$$

Now the linear strain degrees ε can be expressed using these direct relations:

$$\varepsilon'_R = 1 - \frac{\sqrt{R_0^2 + r_1^2 - r_x'^2}}{R_0}\ , \qquad (7) \qquad \text{i.e.} \qquad \varepsilon'_r = 1 - \frac{r_1}{\sqrt{R_0^2 + r_1^2 - R_x'^2}}\ . \qquad (8)$$

In the same way the linear strain degrees for the second phase (ε''_R i ε''_r) i.e. third (last) phase (ε'''_R i ε'''_r) can be expressed, so the graphics of the relative strain degrees for the external ε_R and inner rim ε_r of the cup flange can be drawn, so in the interval $r_1 \le r_x \le R_0$ -actually $20 \le r_x \le 37{,}5$. Those graphics (Figure 2.) are made in Excel 2003 (Table 1.) and OriginPro7.5 , so on the *x*-axis is only the variable radius r_x , and on the *y*-axis are the values of the strain degrees.

Table 1. Strain degrees calculated in Excel 2003

r_1	r_x	R_0	ε_r	ε_R
20	20	37,5	0	0
20	21	37,5	0,047619	0,014686
20	22	37,5	0,090909	0,030327
20	23	37,5	0,130435	0,04697
20	24	37,5	0,166667	0,064669
20	25	37,5	0,200	0,083485
20	26	37,5	0,230769	0,103488
20	27	37,5	0,259259	0,12476
20	28	37,5	0,285714	0,147396
20	29	37,5	0,310345	0,171507
20	30	37,5	0,333333	0,197227
20	31	37,5	0,354839	0,224715
20	32	37,5	0,375	0,254167
20	33	37,5	0,393939	0,285826
20	34	37,5	0,411765	0,32
20	35	37,5	0,428571	0,35709
20	36	37,5	0,444444	0,397634
20	37	37,5	0,459459	0,442386
20	37,5	37,5	0,466667	0,466667

Strain degrees ε_r of the inner rim are higher than the strain degrees ε_R of the external flange rim. They are only equal at the beginning when both of them are equal to zero and at the end when both of them are equal to 0,466. In the diagram it is also visible that the strain degrees are not constant during the process. On this it can be concluded that the deep drawing process in the first operation is non-stationary. Therefore, when calculating neither the minimal nor the maximal relative strain degree of flange is taken but the average, accordingly to the formula :

$$\varepsilon_{sr} = \frac{\varepsilon_r + \varepsilon_R}{2}\ . \qquad (9)$$

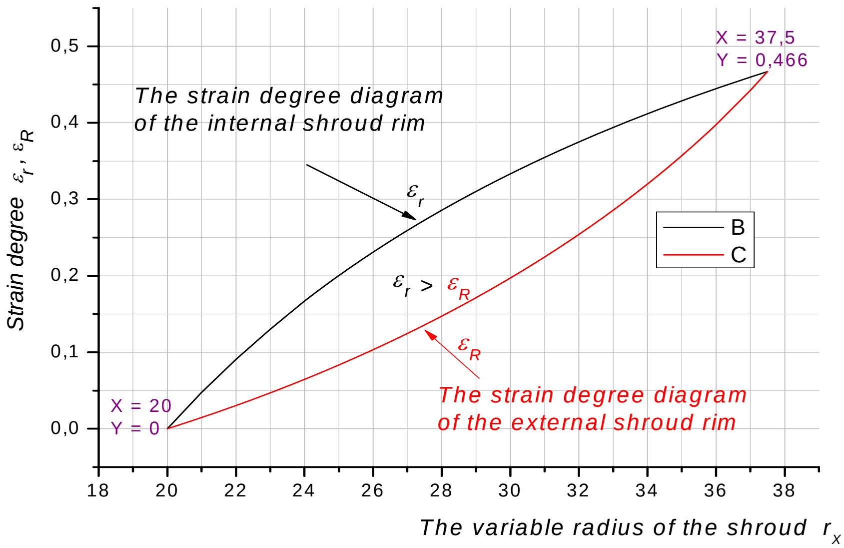

Figure 2. Graph of the flange strain degree flange

3. CONCLUSION

In the paper the formulas are derived for depths and radii of the cup per phases, the values are calculated and all is drawn in AutoCAD. Also the formulas are derived for the relative strain degree of the flange, and their values are calculated in Excel and their graphics are drawn in OriginPro 7.5. It is shown that the inner part of the flange can tolerate more strain than its external with which the non-stationary character of deep drawing in the first operation is proved, because in that operation the cup flange is regularly involved.

4. REFERENCES

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