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EXAMINATION OF THE STRENGTH AND DUCTILITY OF AA-1050 MATERIAL SHAPED WITH THE MULTI-STAGE DEEP DRAWING METHOD

WYTRZYMAŁOŚĆ I PLASTYCZNOŚĆ STOPU ALUMINIUM AA-1050 KSZTAŁTOWANEGO PRZEZ WIELOETAPOWE GŁĘBOKIE TŁOCZENIE

Deep drawing materials are easily shapeable materials, because of their high ductility. Aluminum alloy materials are classified in the deep drawing materials group because they are easily shapeable. In order to increase the strength, materials are made an alloy by adding some chemical additives. They are also provided strength increasing by tempering. Normally, materials harden when reshaped under plastic deformation. Reshape the shaped materials harden while reducing its ductility. In this study, changes in mechanical properties immediately after the AA-1050 (T0) sheet material is shaped by the multi-stage deep drawing method and after storage were investigated. It was calculated that a 4-stage shaping is needed for a tube production at selected sizes. Deep drawing treatments are made in sizes of these stages. Samples were collected from each cold-shaped intermediary form. Mechanical properties of this materials are determined by applying tensile test. Some basic parameters, like tensile stresses, max. uniform strain rates, strain hardenings and strength coefficients, are investigated and compared. Obtained data were explained using graphs. It was observed that tensile strength increased and strain quantities were reduced at every stage. It is also seen an increase in strain hardening index.

Keywords: Al-1050, sheet metal forming, multi-stage deep drawing

Stopy do głębokiego tłoczenia są materiałami łatwo odkształcalnymi z powodu ich wysokiej plastyczności. Stopy aluminium należą do grupy materiałów odpowiednich do wytłaczania, ponieważ są łatwo odkształcalne. W celu zwiększenia wytrzymałości, do aluminium dodawane są pewne dodatki stopowe. Wytrzymałość wzrasta także po odpuszczaniu. Zwykle, materiały umacniają się wskutek deformacji plastycznej, co wiąże się ze zmniejszeniem plastyczności. W tej pracy, badano zmiany właściwości mechanicznych stopu AA-1050 (T0) bezpośrednio po odkształceniu przez wielokrotne głębokie tłoczenie oraz po okresie przechowywania. Obliczono, że do produkcji rur w wybranych rozmiarach potrzebne jest 4-etapowe odkształcenie. Próbki do badań pobrane były po każdym etapie odkształcenia na zimno. Właściwości mechaniczne tych materiałów zostały zbadane przez zastosowanie próby rozciągania. Niektóre podstawowe parametry, takie jak naprężenie rozciągające, maksymalna jednorodna prędkość odkształcenia, umocnienie po odkształceniu i współczynniki siły, zostały zbadane i porównane. Uzyskane dane zostały przedstawione za pomocą wykresów. Stwierdzono, że wytrzymałość na rozciąganie wzrasta a stopień odkształcenia maleje po każdym etapie odkształcenia. Obserwowano także wzrost wskaźnika umocnienia odkształcenia.

1. Introduction

Deep drawing operation is frequently used in the production of one side shut cylindrical cups and similar items in industry. The sheet piece which will be formed in that production operation, has been set into die as seen in Figure 1-a and apply pressure with a blank holder vertically. Then the sheet between blank holder and die is transformed into cup under plastic deformation, by applying a vertical pressure by a punch which moves vertically to the workpiece [1,2].

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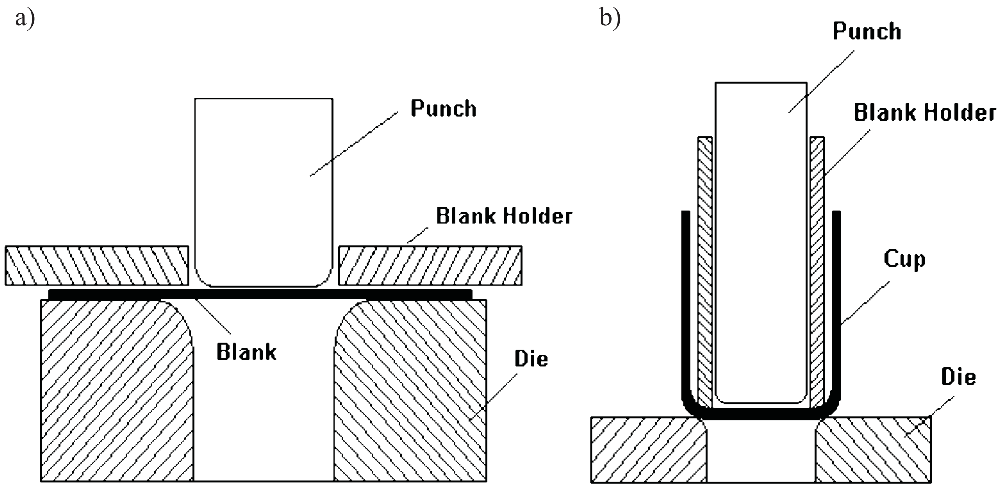


Fig. 1. The schematic view of deep drawing operation a) First step b) Next steps

Materials transformed into cup by deep drawing method are reshaped for transformation into another cup form with a narrower diameter as seen in Fig. 1-b, and the multi-stage deep drawing operation is made. In the end of each step, hardenings occur and the material may be torn[3].

When the shaped cups are subjected to static aging by storage, changes occur in the ductility and strength of the material [4]. This change affects the cup efficiency [5]. Stress-strain curves of materials subjected shaping under plastic deformation reveal very important information about the mechanical properties of that material. So, it becomes important to know the mechanical behaviors of deep- drawn sheets.

Since the 1970's, the researchers have extensively covered the strain curves formed during the shaping of sheets [6]. In order to simplify complex strain path changes, pre-straining in tension (Raphanel et al.) [7], rolling (Wagoner and Laukonis) [8] and simple shear was followed by tension (Schmitt et al.) [9] or shear (Rauch and G'Sell) [10] at different orientations, exhibiting peculiar behaviors like work-hardening stagnation in the case of Bauschinger effect, related to the partial dissolution of the dislocations, or stress softening after reaching a maximum value in the case of orthogonal strain path change, which corresponds to the activation of slip systems during the second loading that were latent during pre-straining. Thuillier and Rauch [11] showed that this stress softening is associated to a localized plastic flow in microbands. In order to quantify the effect of the strain path change, Schmitt et al. [12] proposed a single parameter defined as the cosine of the angle in the strain space between the strain rate tensors during the pre-strain and the subsequent strain path. Studies of Bouvier et al. [13], Haddag et al. [14,15] and Flores et al. [16] have dealt with the influence of such a complex constitutive equation on the prediction of several forming process parameters at room temperature, when compared to a mixed hardening.

In order to be able to make multi-stage deep drawings, an experimentation setup is set up as seen in Figure 2. This setup contains a single-acting type C hydraulic press and a blank-holding drawing mold assembly specially designed and produced for this job. This mold assembly has its own independent hydraulic power unit. Pressure forces of the press and the blank-holding die can be independently controlled.

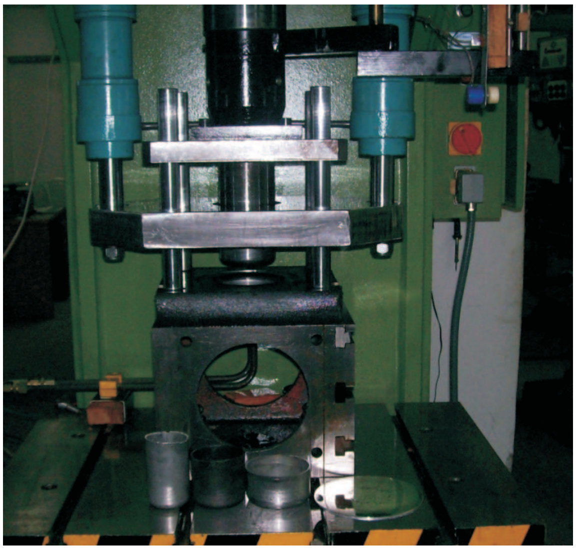


Fig. 2. Experimental mechanism

A double hydraulic cylinder with equal properties is fitted to press the blank holder. To make sure the blank holder homogenously presses to the sheet surface, the cylinders were symmetrically fitted and the blank holder is designed so that it shall move on 4 guiding bars.

2. Experimental study

In this study, we aim to produce a cup, 50 mm in diameter and 100 mm in height. It was calculated that a 4-stage drawing operation is needed in order to be able to obtain a cup with the aimed sizes.

Mold sizes are calculated by the following equations no (1-5) [17];

Punch Diameter (d) : $d_1 = m_1 D, d_n = m_n d_{n-1}$ (1)

(for 2 mm Aluminum m_1 *= 0.55 ,* m_n = 0.80)

Cup height (h) : $h_n = (D^2 - d_n^2\ )/(4xd)$
n=stage number (2)

Punch radius (R) : 5e<R<10e or R=(0.1...0.3) d_n (3)

Die radius (r) : $r_n = 0.9\sqrt{(D-d)\,e}$ (4)

Die gap (w) : w= $e + 0.02\sqrt{10\,e}$ (5)

Mold sizes calculated for each drawing stage are shown in Table 1 by the help of Figure 3.

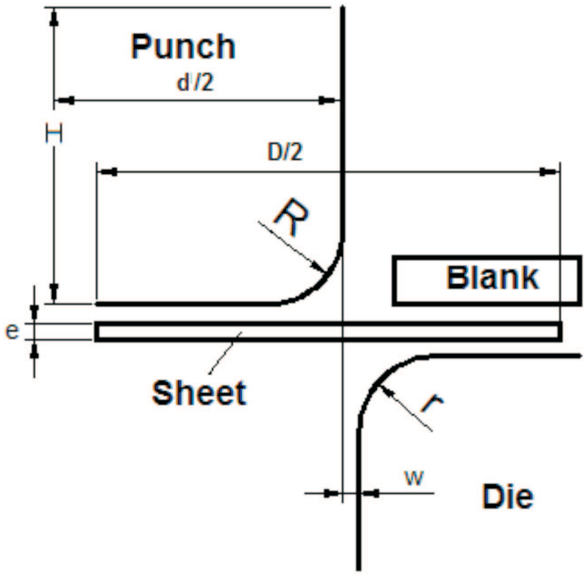


Fig. 3. Symbolic representation of the die dimensions

TABLE 1

Dimensions of the drawing stages

	St. 1	St. 2	St. 3	St. 4
d	84	68	54	42
h	46	66	91	117
R	12.7	10	9	7
R	10	8	7	6
W	2.1	2	2	2
H	80	90	130	160
D= 150 mm **e=** 2 mm				

The shaped cups until 4. stage of unshaped sheet material are displayed in Fig. 4. Since reached to aimed height at 4 stages, the mechanical features of 4 stage are taken under examination

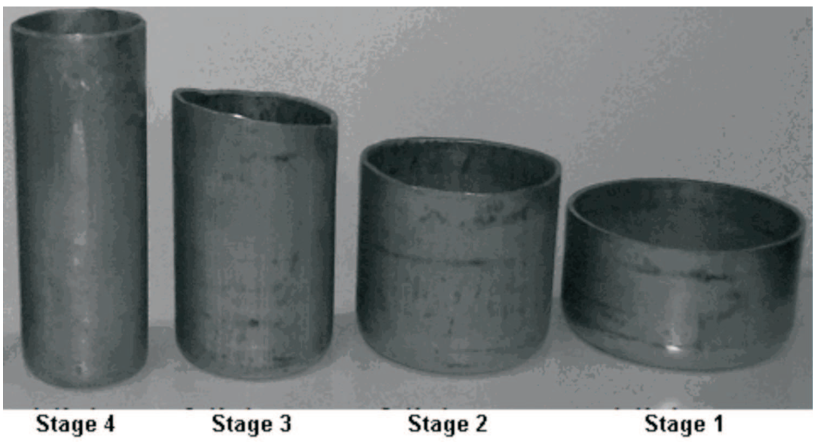


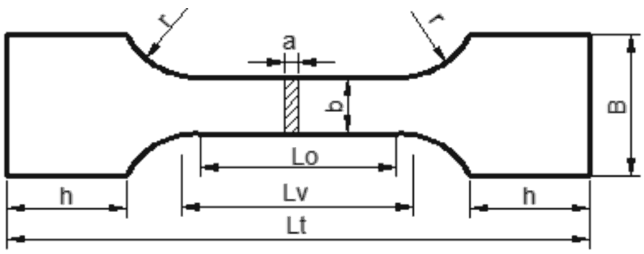
Fig. 4. Cups which are shaped until 4th stage

Fig. 5. Cutting out places of tensile test specimens

During deep drawing operation material heaping occures in flange part. In addition to this, the movement of cup's rim part are made difficult because of the blank holder pressure. On the contrary, drawing force to sheet are applied in direction of punch axis related to punch motion. Therefore, the region where material flow was most intensive was the wall region, which remained under the blank holder at the start of drawing, and deformed and formed the wall of the cup on its vertical axis at the end of the drawing. It was considered that hardenings would increase as the largest plastic deformation occurred in these regions. To do this, specimens to study the mechanical properties were taken from these regions. Regions where the specimens were taken according to drawing stages are shown on the cup in Figure 5.

Drawing test specimens were prepared in dimensions complying with the standards shown in Figure 6. While a test specimen with a total length of 50 was preferred for stage 1 and 2 specimens where cup heights were insufficient, specimens with a total length of 65 were preferred for the others.

All specimens were obtained with the help of a custom-made cutting die with concerns of deformation in material properties during aluminum material processing. Chemical composition of the material given in the literature is shown in Table 2.



a	b	B	Lo	Lv	r	h	Lt
2	8	20	28	33	4	12	65
2	5	15	21	24	3	10	50

Fig. 6. Standard shape tensile specimens

TABLE 2

Chemical composition of AA-1050 [18]

Fe	Si	Zn	Ti	Mg	Mn	Cu	Al
0,4	0,25	0,07	0,05	0,05	0,05	0,05	99,5

3. Experimental Results

Stress-strain curves of specimens collected from cups made by shaping at 4 stages while a raw sheet are given in Figure 7. Places where the uniform strain change starts and finishes are shown by small circles. For convenience of study, the line in between these two points was thickened.

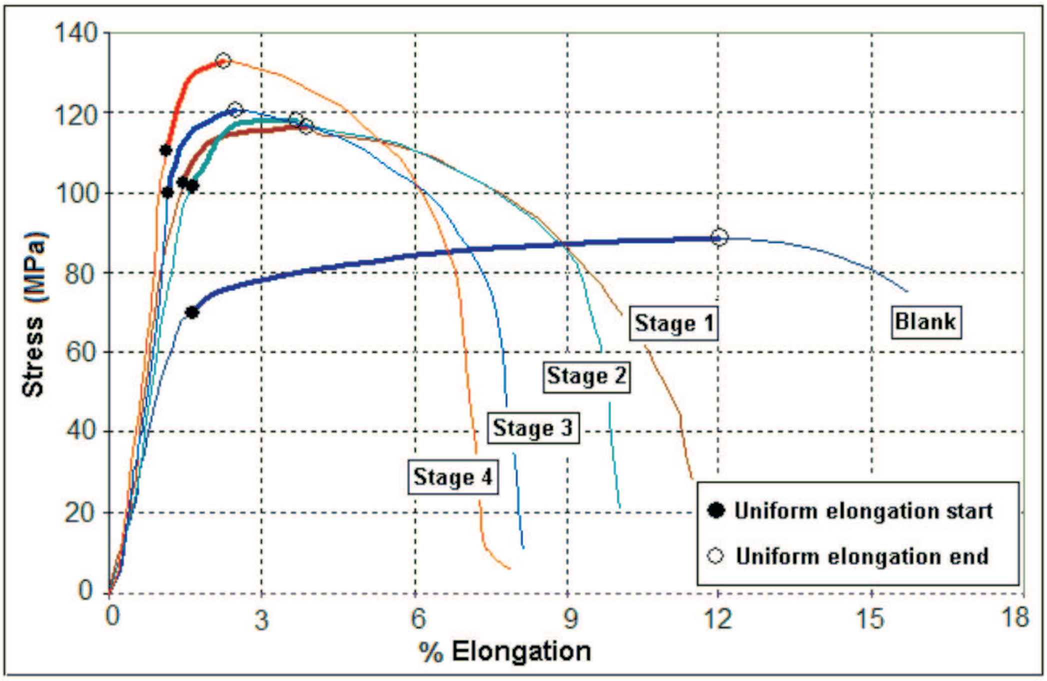


Fig. 7. Stress and strain curves for unshaped sheet and cups formed under 4 different stages

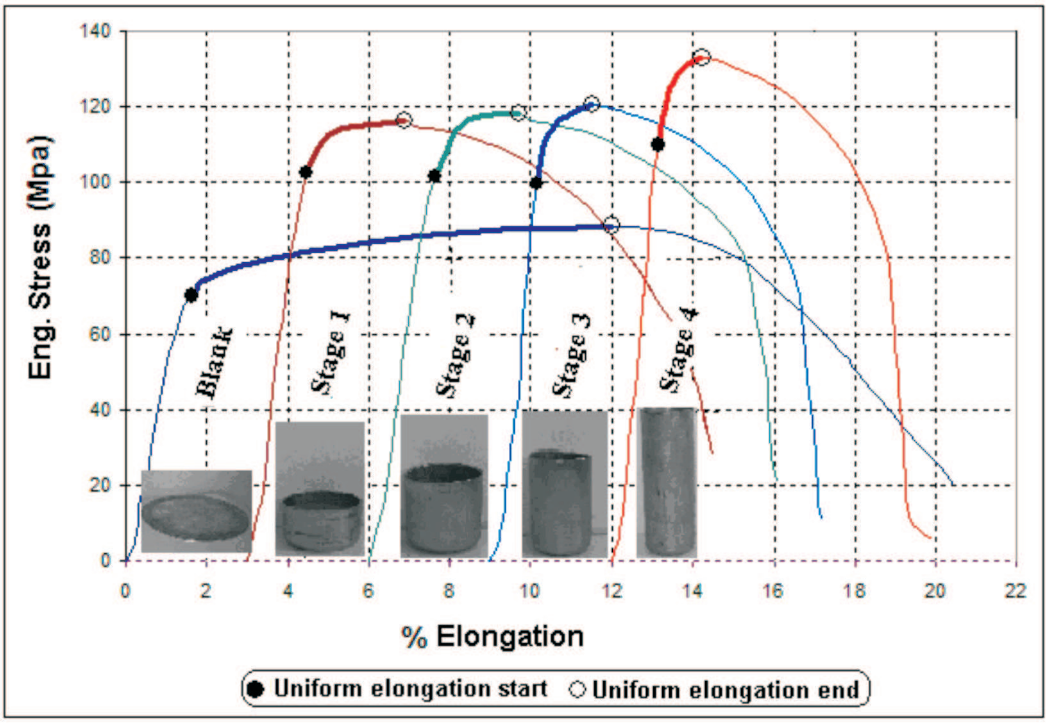


Fig. 8. Consecutive representation of stress-strain curves for blank and cups obtained at 4 stages

Another representation of tensile tests belong to each drawing stage are displayed consecutively in Fig. 8 as well. When Fig. 7 and 8 are taken up together, tensile strength of blank are measured as 88.4 MPa. Engineering strain (e_u) which is at max. tensile strength (σ_u) is seen as 12.

In 1th stage forming, while σ_u value shows %31 increase relatively to blank, there is a decrease around % 50 in e_u value.

In 2nd stage forming, while σ_u value shows %33 increase relatively to blank, there is a decrease around % 69 in e_u value.

In 3rd stage forming, while σ_u value shows %36 increase relatively to blank, there is a decrease around % 79 in e_u value.

In 4th stage forming, while σ_u value shows %50 increase relatively to blank, there is a decrease around % 81 in e_u value.

When a comparison is made between stages;

while the σ_u valu in 2^{nd} stage shows a %1.02 increase in comparison to the σ_u value in 1st degree, it is seen a decrease around %5 in e_u value.

while the σ_u valu in 3^{rd} stage shows a %1.02 increase in comparison to the σ_u value in 2nd degree, it is seen a decrease around %32 in e_u value.

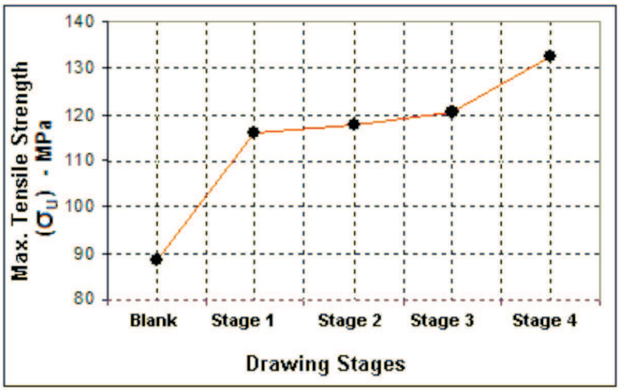
while the σ_u valu in 4^{th} stage shows a %1.10 increase in comparison to the σ_u value in 3rd degree, it is seen a decrease around %10 in e_u value.

In Fig. 9-a, maximum tensile strength are displayed according to stages. In Fig. 9-b maximum uniform elongation values are showed according to stages, as well.

When the diagram in Fig. 8 and 2 diagrams in Fig. 9 are evaluated together, it can be seen that tensile strength increases with increased drawing stages, whereas ductility is continuously reduced.

When the numerical values, which are visualized comparatively in Fig. 8 and summarized as stress-strain expression at maximum uniform elongation point in Fig. 9, are collected in a table, the result in Table 3 comes out.

The correlation between tensile stress and strain hardening exponent in uniform strain is as seen in Eq. 6. In this equation, K shows the strength coefficient, and ε shows the true strain value.



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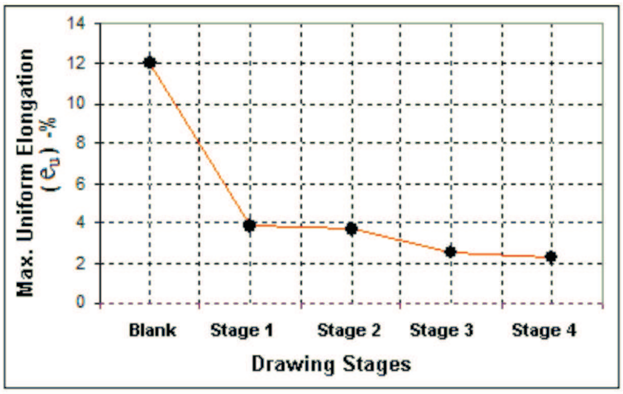

-b-

Fig. 9. σ_u and e_u values according to drawing stages

$$\sigma_u = K\varepsilon^n \tag{6}$$

True strain value is calculated by Eq. 7 based on the engineering strain ($e_{eng.}$) value.

$$\varepsilon = \ln(1 + \frac{e_{eng.}}{100}) \tag{7}$$

TABLE 3

Some mechanical values of AA-1050 by drawing stages

Stages	Max. Tensile Strength σ_u – (MPa)	Engineering Strain eu – (%)	True Strain €u – (%)	Strain Har. Exponent n	Strength Coeff. K
Pot	88.37	12.02	0.114	0.17	143.45
Stage-1	116.07	3.88	0.038	0.18	214.64
Stage-2	117.94	3.69	0.036	0.21	244.01
Stage-3	120.52	2.51	0.025	0.26	327.46
Stage-4	132.60	2.26	0.022	0.29	408.74

Hardenings in the material were obtained from the formula in Equation 8, by ultimate tensile strength (σ_u), yield stress (σ_A), true strain value at the ultimate uniform strain point ($Ş_u$) and true strain at the flow point ($Ş_A$) value.

$$n = \left(\frac{\log \sigma_u - \log \sigma_A}{\log \varepsilon_u - \log \varepsilon_A}\right) \quad (8)$$

ε and K values at the uniform strain region of each stage are given in Table 3.

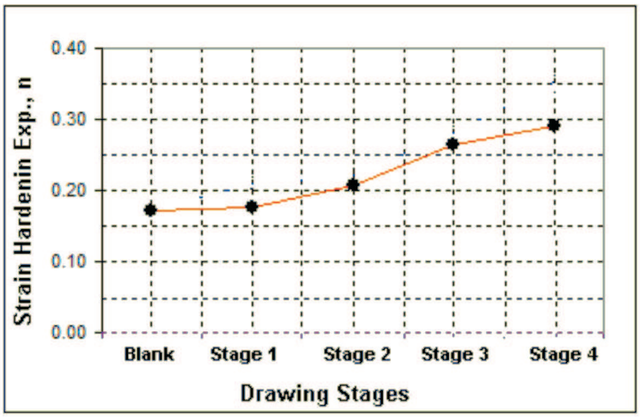

Fig. 10. Strain hardening values by stages

It is seen that strain-hardening exponent also increases as the material strength increases with an increase in drawing stages. A reduction in ductility with an increase in strength also increases the tilt angle at the uniform strain region. It affects the strain-hardening exponent, a factor of this tilt.

When strain hardening values in Fig. 10 and Table 3 are observed, there is an %70 increase between 4^{th} stage and blank. In each stage, Strain hardening exponent value shows an average %17.5 increase in comparison to previous stage.

4. Conclusions

As deep drawing materials are easily shapeable, their strengths are lower compared to other materials. However, multi-stage shaped soft materials that will be ultimately used as a pressure cup require a higher strength requirement. With this purpose, although it is a negative outcome that as drawing stage increase the ductility of material reduces, increasing of the hardening is a profit in terms of cup yield. Four times more reshaping of the unshaped material is important because of strength gain. For this reason, untempered AA-1050 materials chosen as reference were shaped into tubes using the multi-stage deep drawing method, and drawing tests were applied on specimens taken from regions subjected to high deformation. As a result of these tests, strength and ductility studies were prioritized. The outcomes of this study are itemized below:

- When materials shaped into cups are repeatedly drawn, the tensile strength of the material increases.
- The material ductility is reduced as the drawing stage increases.
- As the drawing stages increase, strain-hardening exponent of the material increase too
- After 4 stage drawing, There is a %40 increase in the material's strength
- After 4 stage drawing, There is a %81 decrease in the material's ductility

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