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Sheet Formability Using Hemi-Spherical Punch And Rubber Die

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Abstract.

In recent years, the elastomer forming technique has found acceptance on the shop floor and is used increasingly as a pressure- transmitting medium for various metal-forming operations. This is due mainly to the introduction of a new range of materials and of new concepts in tooling, which have served to kindle industrial interest in the process.

The purpose of this paper is to study the sheet formability with compressible die (natural rubber). The forming was occurred using hemi-spherical punch and rubber die. Experimental tests were used to know the mechanical properties for rubber and sheet materials which were brass and aluminum. After that several forming processes were prepared with a 58 mm diameter steel ball as a punch to form 0.5 thickness brass and aluminum dishes with different diameters (15-40 mm). Force-stroke history was plotted through forming to find the stiffness of formed plate with rubber die and later to compare this parameter for different diameters. Wrinkling and springback were pointed for the formed dishes. It was found that the stiffness of the formed dish increases with diameter until reaching to the diameter at which wrinkling will takes place (about 33 mm for aluminum and 28mm for brass), and then the stiffness will decreases with diameter above this value. It was found that the springback ratio (ratio of final high to the stroke) was increased with diameter until wrinkling takes place, and this ratio is greater for aluminum than that for brass.

The results show that it is able to use natural rubber as a die for sheet metal forming with limitation of using small sheet thickness.

Keywords: SMF (sheet Metal Forming), springback, wrinkling, rubber die, sheet formability.

1. Introduction.

Elastomer tooling has been used in the industry for thirty years ago, furnishing a wide variety of examples of its applications. This type of tools are successfully designed into a very wide rang of presswork [1]. However, despite its long existence and versatility, the technique has not yet come into full industrial use. This is due to partly to a lack of understanding of the process variables, and partly because manufacturers are very reluctant and existing plant that works well and is already amortized. It is hoped that in the near future, industry will recognize the major contribution that the process can achieve.

There are a lot off works dealing with rubber forming as that in forming tires [2], adding additives[3,4,5], and yet there are new publishers working and treating the rubber and its applications.

These days natural rubber is treated to give it cross links, which makes it an even better elastomer. When rubber is cross linked it won't melt when it gets hot. That's why rubber car tires don't melt when driven really fast, even though they get very hot from friction with the road [6].

The defects occurs through the SMF of axi –symmetrical forming are springback and wrinkling and the works on these defects are starting from the beginning of the past millennium [7] for wrinkling and after the second war for springback [8]

2. Theory.

When the punch first touching the circular blank resting symmetrical in the die, it does so its mid-point, as the punch advanced, contact with blank occurs over a circle, the radius of which moves outwards as the punch descends; for the rubber die there is no loss of contact as the punch descends while, it is for rigid die[9].

At the moving contact circle it is supposed that a plastic circle hinge is created. **Fig. (1)** shows the reactions when the punch presses the blank and so the rubber pad and the deformation feature through the forming. It can be noted that the deformed load consists mainly of the following parts:

(a) Load required to compensate for the displacement volume of the rubber within the forming vicinity (F_d)

(b) Load required to overcome the bending resistance of the material (F_m)

This load depends upon the thickness of the stock, the radius of the die, and the surface condition. It should be also note that a tight fit is assumed between the rubber die and the container wall, so that the container is considered to be completely filled with rubber prior to the compression process.

The load required to displace a certain volume of rubber without the blank is then given by the following equation

$$F_d = E_c S A_t v_d / V \qquad 1$$

Where the shape factor (S) is defined as the ratio of the loader area to the surface area of the pad (e.g. $\pi r_i^2 / \{ 2\pi r_i h \} = r_i / 2h$). The displacement volume of rubber (v_d) is governed by the ram displacement (δ) and the punch radius (R) in the case of hemi-spherical tool. This was yielding:

$$v_d = \int_0^{\delta} \pi\{ R^2 - (R - y)^2 \} dy = \pi\delta(4R^2 - 3R\delta + \delta^2) / 3 \qquad 2$$

The load necessary to form the sheet metal alone into the dish shape is expressed as [9]

$$F_m = \frac{2\pi R M_P \sin\phi \cos\phi}{(r / R - \theta) \cos(\phi - \theta)} \qquad 3$$

Where θ is the half angle for fully plastic, which can be evaluated from

$$sin\,\phi = \frac{R}{(R+t)}[sin\,\theta + (r/R-\theta)cos\,\theta] \qquad 4$$

Therefore, the total bending load (F) required for the forming dish using hemi-spherical punch and rubber die can be expressed as follows:

$$F = F_d + F_m = E_c S\,A_t\,v_d\,/V + \frac{2\pi R M_P\,sin\,\phi\,cos\,\phi}{(r/R-\theta)cos(\phi-\theta)} \qquad 5$$

The stiffness of the forming is equal to the ratio of load to ram displacement (F/δ)

3. Experimental work.

In general, the bending tools for use with rubber die are simple to construct and to put into practice. The tools, which are shown in **Fig. (2)** contained essentially of a die container, which encases or houses the rubber pad and avoids the side spread of the material during the punching operation, and a punch.

The balls used as hemispherical die were (33mm, 42mm and 58 mm) used for bearings as shown in **Fig. (3.a)**. The tests results shows wrinkling for small diameter die therefore the parameter work were based on 58 mm diameter die only. The initial is for using square and circular plates, also the wrinkling was taking place for square plat and buckling was occurring in the shortest diagonal of the square as shown in **Fig. (3.b)**. Then the tests were carried for circular plates only. Two materials were used which were Commercial Aluminum sheet **Fig. (3.c**) and brass 70:30 sheet **Fig. (3.d**). Plate diameters were (15, 20, 25, 30, 35, 40 mm).

The mechanical properties of the sheet materials were measured using standard tensile test, which are shown in **Fig. (4)**.

4. Results and Discussion.

The load history through the forming process was recorded and plot versus the advance of the punch in **Fig. (5**) for aluminum sheets and in **Fig. (6**) for brass sheets for different diameter of formed sheet, it was shown that the load was increasing as the displacement increases which is known phenomena due to resistance of the material to deforms according to the stress strain relation. The value of force needed was higher for the sheet has higher diameter because as the diameter increase the amount of material which resist the load will increases and so the stiffness increase causing increase in the load as shown **Fig. (5)** and **Fig.(6)**.

The tests were carrying maximum load of 1kN for reason of the limitation of load which the rubber pad can resists, the tests and trail to increase the load over this amount causing failure and cutting in the rubber bad, the tests showed that the maximum allowable load can be applied is about 2kN, therefore the safer load used was1kN

It was shown that the brass need more forming load than aluminum for the same forming stroke, because of the mechanical properties.

The stiffness of the formed plate through forming was ploted againest the diameter of the plate for aluminum and brass in **Fig. (7)** and **Fig. (8)** repectivelly, it was shown that the stiffness was increased with diameter until reaching the diameter reaching the value which wrinkling takes place then the stiffness will decrease due to circumferntial buckling which observe the forming load and cause the wrinkling waves which can be cleary shown in **Fig.(9)**. the critical value for diameter where above it buckling occurs is found to be 33mm for aluminum blank and 28 mm for brass blank.

The resultant stroke, vesible Hieght, Final Height after unloading, springback ratio (ratio of final hieght to the vesible loaded hieght) and springback percentege (percentege of hiegth defference to the final hieght) were tabulated in **table (1)**, for Aluminum and Brass. Theses results were drawed through **Fig. (10)** to **Fig. (14)**. It was shown that spring back error for brass is greater than that of aluminum because the brass has more rate of work hardening and we were concluding earlier that the work hardenig was doing to increase springback error [10,11], this was agree also with other [11]. Also when wrinkling start through forming (spacially for higher diameter of plate), the springback will be vanishes due to circumferential buckling in the wrinkling which was not return through unloading.

Fig.(10) shows clearly that the point where the wrinkling starts has a lower stroke for aluminum (when d=33mm) and for brass (d=28mm), then the load will stroke return to increase due to lateral buckling and increases in the stifness. However the vesible height of plate remaine increase with diameter befor of kinamatic relation (increase the radius give increases in height at the same angle) as shown in **Fig. (11)**. The final Height after unloading was ploted versus disk diameter in **Fig. (12)**. it was shown that the final height was incresed with increasing diameter for the same resone of kinamatic relation above. **Fig. (13)** and **Fig.(14)** show that the sprinback was decreased with disk diameter because of as the diameter increases the compression on the disk will inceases and this causes decreasing in springback as in [10] and [12].

5. Conclusions.

The main conclusions through this work can be summarized as follows:-

1. The forming stiffness was increasing with increasing diameter until wrinkling takes place then the stiffness will decreases due to circumferntial buckling which obsorve the forming load and cause the wrinkling waves.
2. The value of diameter which the buckling occurs is found to be 33mm for aluminum blank and 28 mm for brass blank with thickness of 0.5 mm.
3. The springback defect through sheet metal forming for brass is greater than that of aluminum.
4. The springback will be vanishes when the circumferential buckling in the wrinkling tacks place.
5. The using rubber as a die in sheet metal forming process was available with sheet diameter less than the punch diameter, above that the wrinkling will occurs.

6. References.

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7. Nomenclatures.

E	Modulus of elasticity	MPa
E_P	Plastic modulus	MPa
n	Work hardening index	-
F	Total bending load	N
F_d	Load required to displace a certain volume of rubber	N
F_m	Load required to overcome resistance of material	N
E_c	compression modulus of elasticity of rubber	MPa
S	Shape factor	-

A_t	Current cross sectional area of steel punch	mm^2
v_d	Displacement volume of rubber	mm^3
V	Original volume of the rubber pad	mm^3
h	Thickness of the rubber pad	mm
δ	Total ram displacement	mm
t	Thickness of sheet metal	mm
R	Radius of steel punch	mm
R_F	Final radius of curvature of the formed blank	mm
r	Blank radius	mm
r_l	Load blank radius (loading)	mm
r_F	Final blank radius (after unloading)	mm
k	Die opening factor	-
M_p	$=\sigma_y t^2/4$ Plastic bending moment per unit length	N
ϕ	Half angle of contact	rad
θ	half angle for fully plastic.	rad
D	Disk diameter	mm

Table(1): Springback Results (Rubber Thickness =21mm,Die diameter = 58mm and plate thickness=0.5mm)

	Diameter*(mm)*	15	20	25	30	35	40
Aluminum	stroke (mm)	8.5	8.2	8.2	8.0	7.2	7.4
	Visible Height under load (mm)	1.1	1.78	2.8	3.86	4.94	6.45
	Final Height(mm)	1.05	1.7	2.69	3.73	4.92	6.44
	Springback ratio	1.076	1.065	1.0446	1.035	1.0102	1.0047
	Springback percentage	7.619	6.471	4.461	3.485	1.0163	0.4658
Brass	stroke (mm)	6.86	6.5	5.5	5.3	6.2	5.7
	Visible Height under load (mm)	1.1	1.3	1.9	2.48	3.14	3.69
	Final Height(mm)	0.93	1.12	1.8	2.44	3.1	3.66
	Springback ratio	1.183	1.17	1.06	1.02	1.01	1.01
	Springback percentage	18.3	16.9	5.8	1.8	1.15	0.75

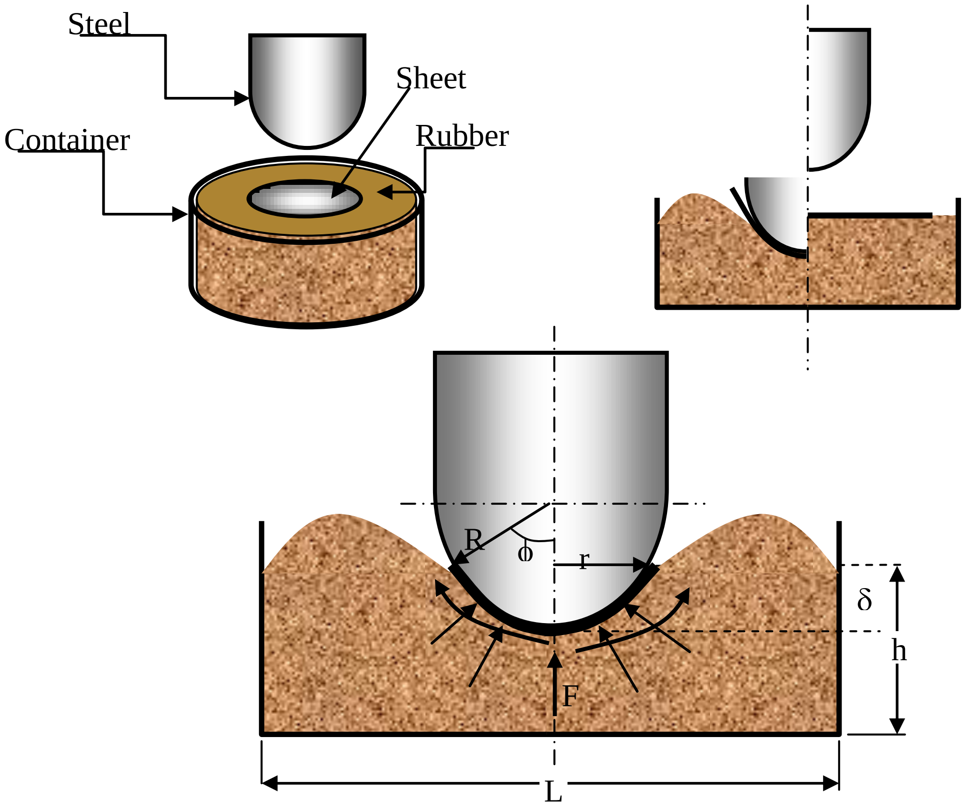


Fig. (1): Schematic showing the model of deformation**.**

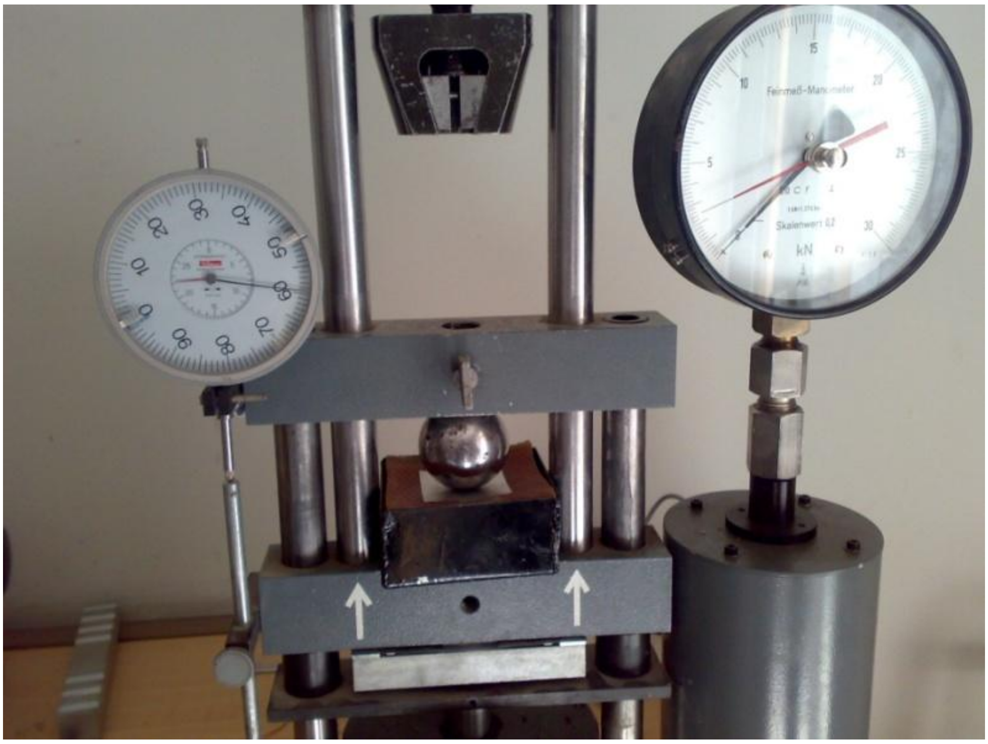
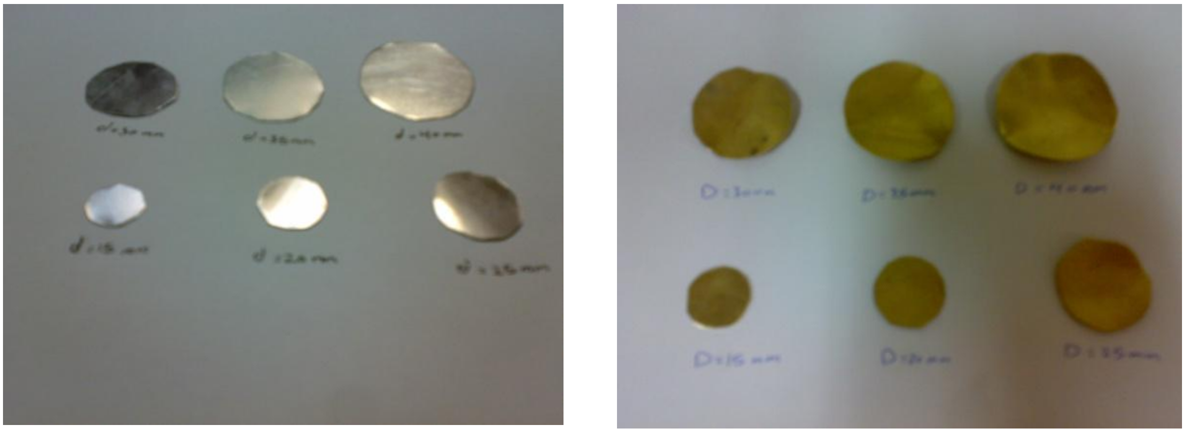


Fig. (2): Forming tools with rubber die.

(a) Bearing Balls as dies.

(b) deformed square aluminum plate.



(c) Aluminum plates.

(d) brass plates.

Figure (3): Dies and plates.

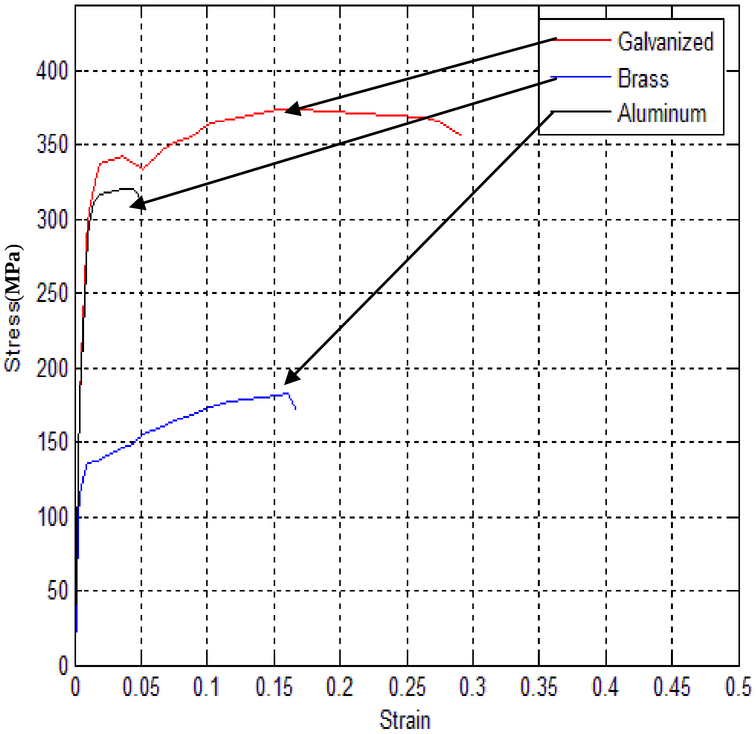


Fig. (4): The resultant tensile test of the materials used.

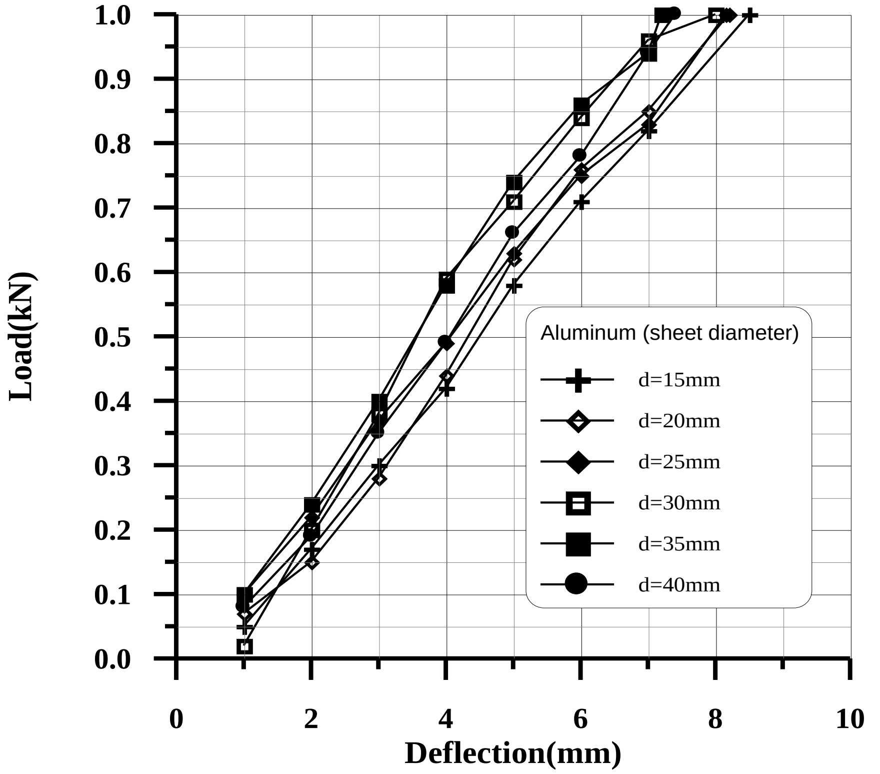


Fig. (5): Load vs. deflection plot for aluminum, maximum load (1kN).

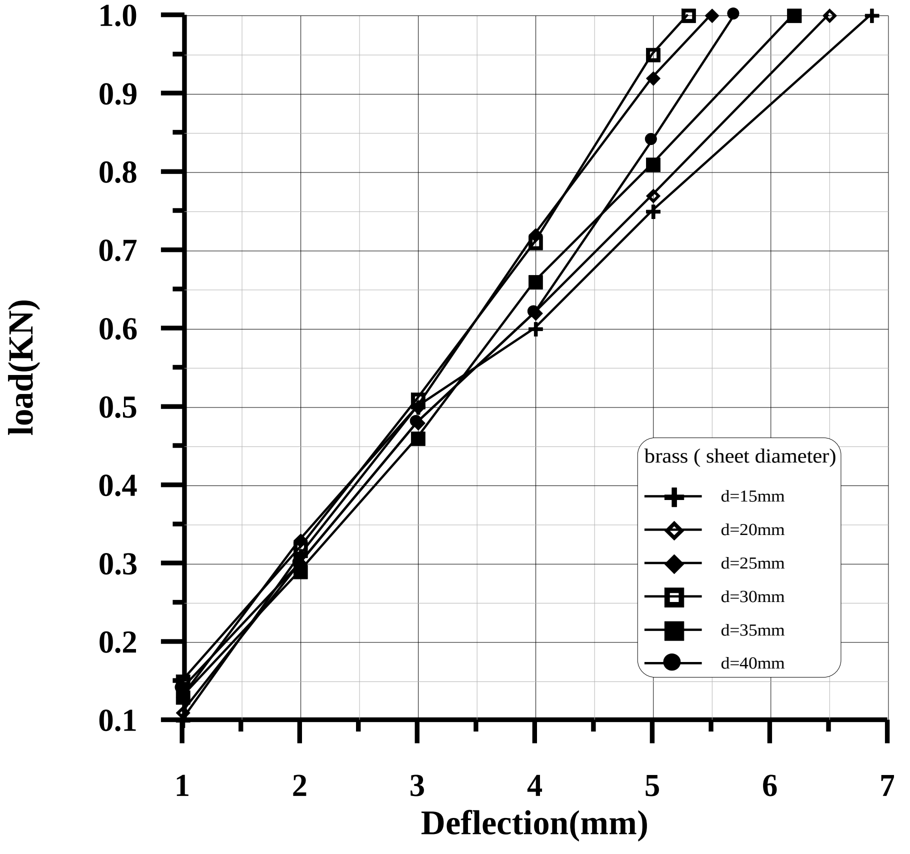


Fig. (6): Load vs. deflection plot for brass, maximum load (2KN).

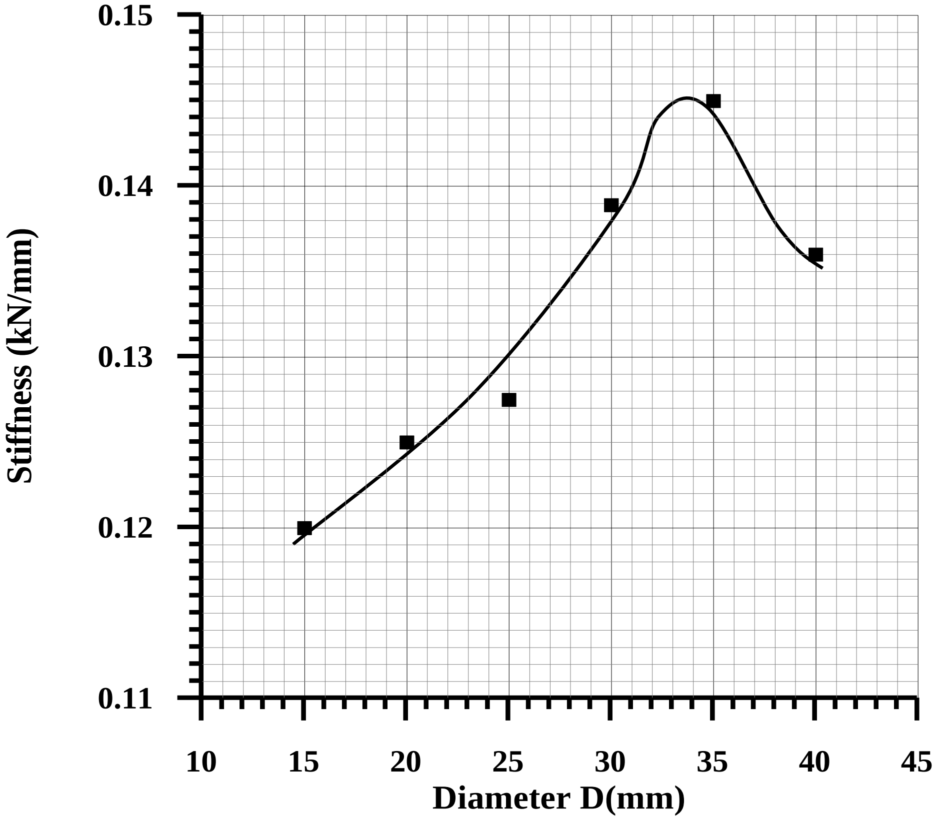


Fig. (7): Diameter-stiffness relation for aluminum.

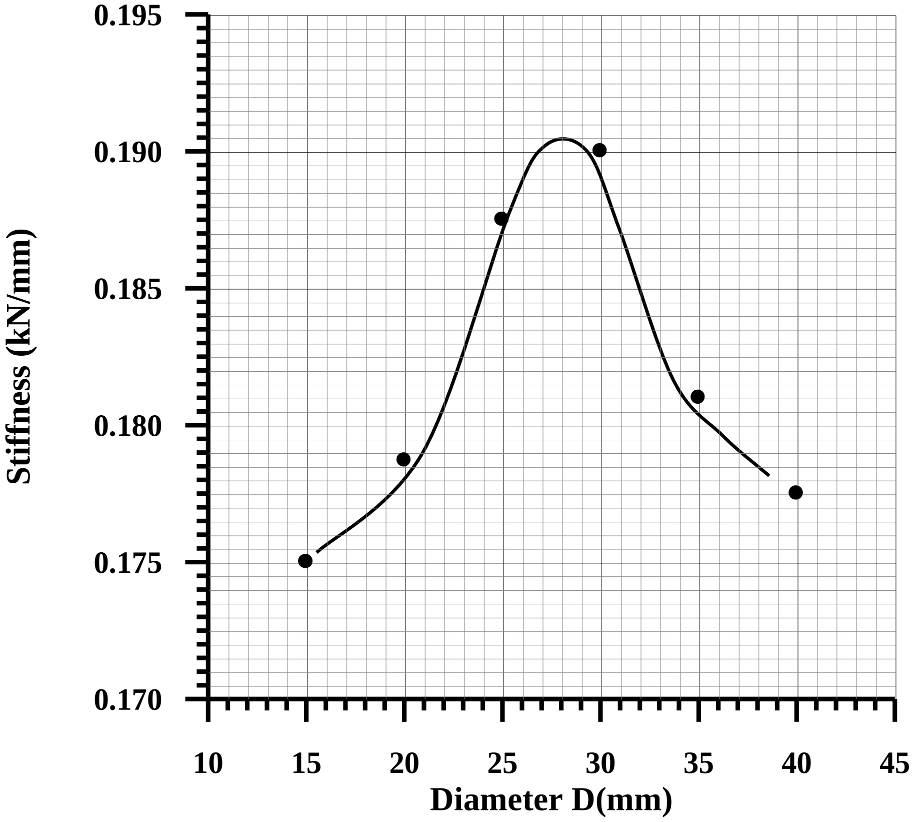
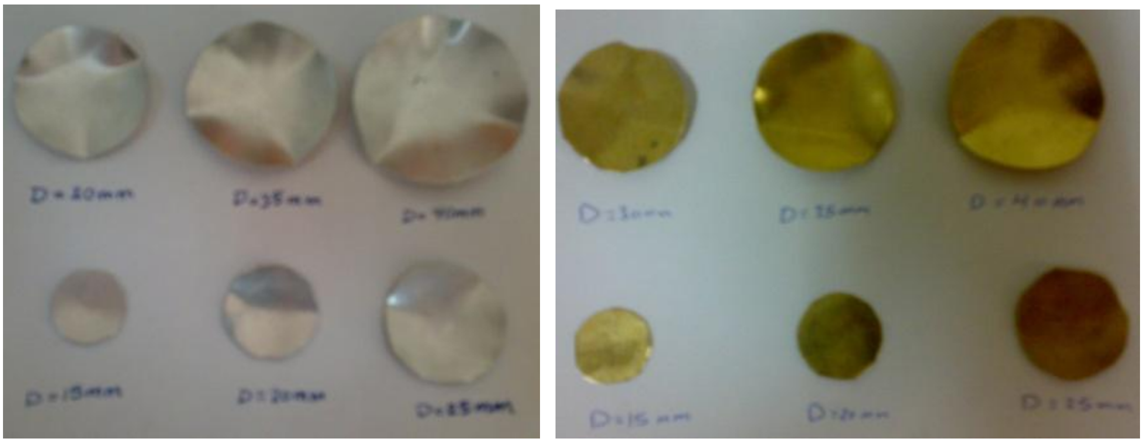


Fig. (8): Diameter-stiffness relation for brass.



Aluminum Brass

Fig. (9): Deformed sheets.

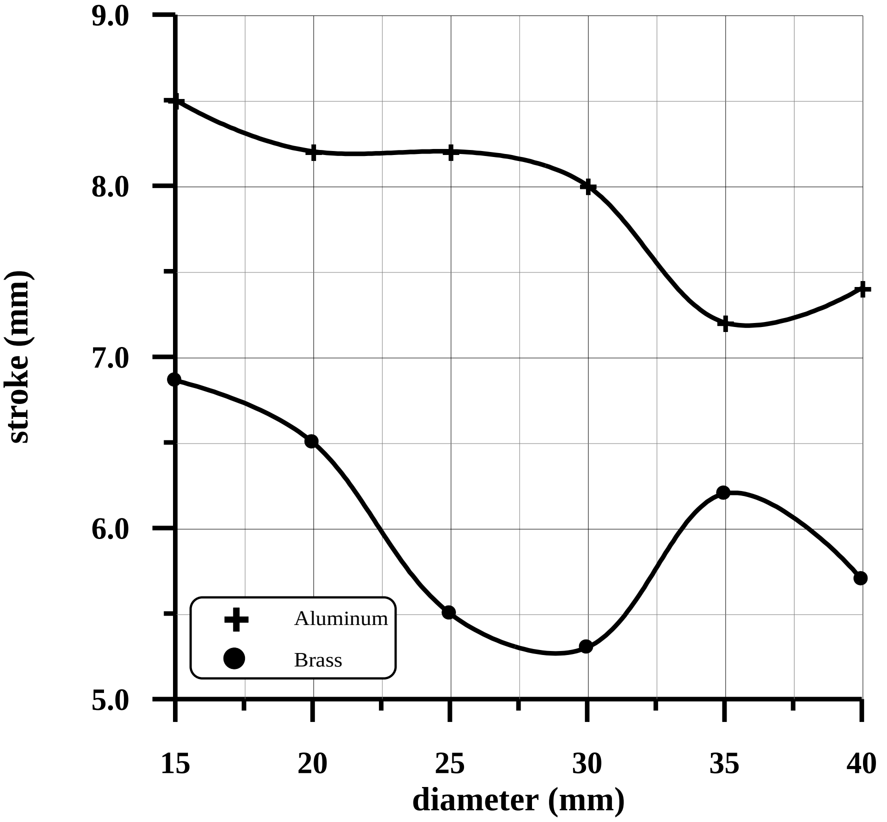


Fig. (10): Strokes versus diameter of disk.

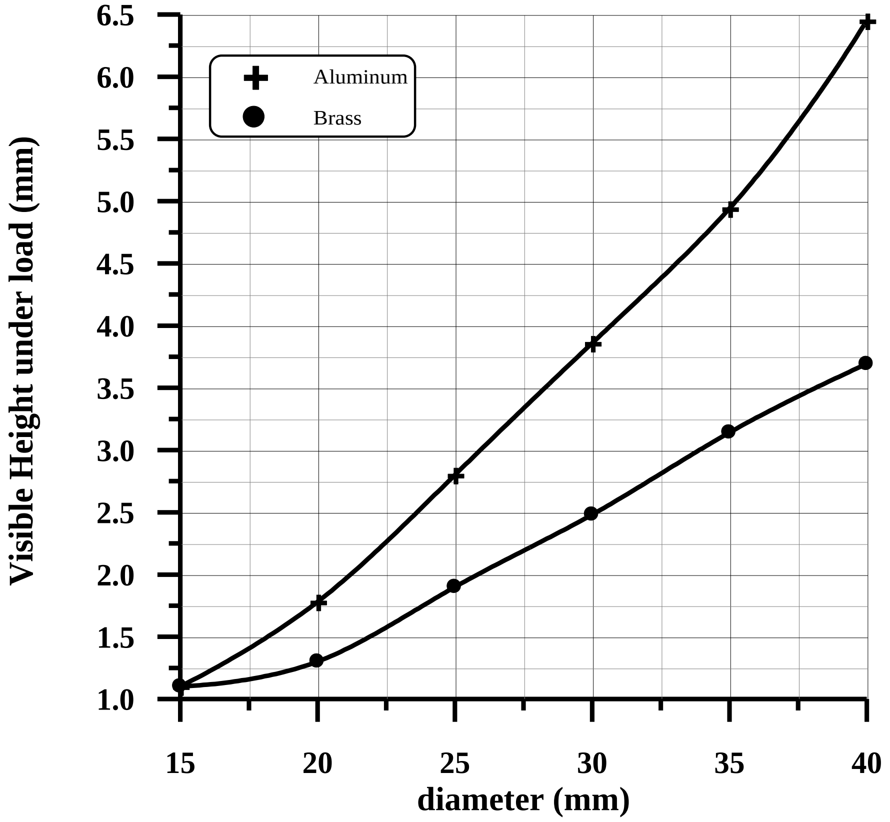


Fig. (11): Visible height under load versus diameter of disk.

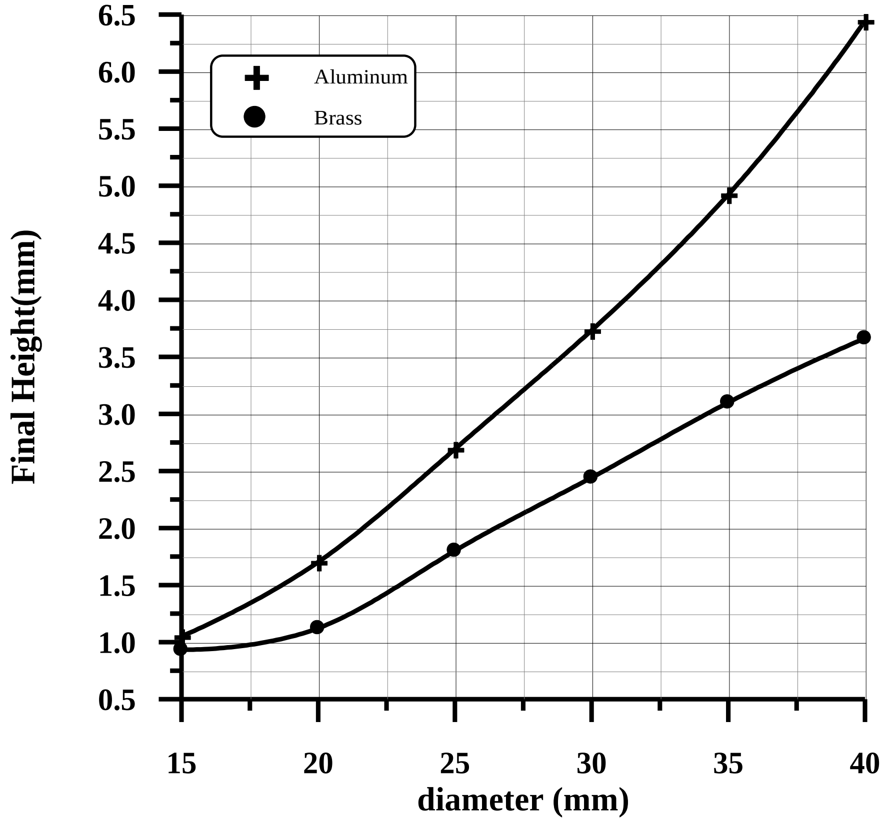


Fig. (12): Final height versus diameter of disk.

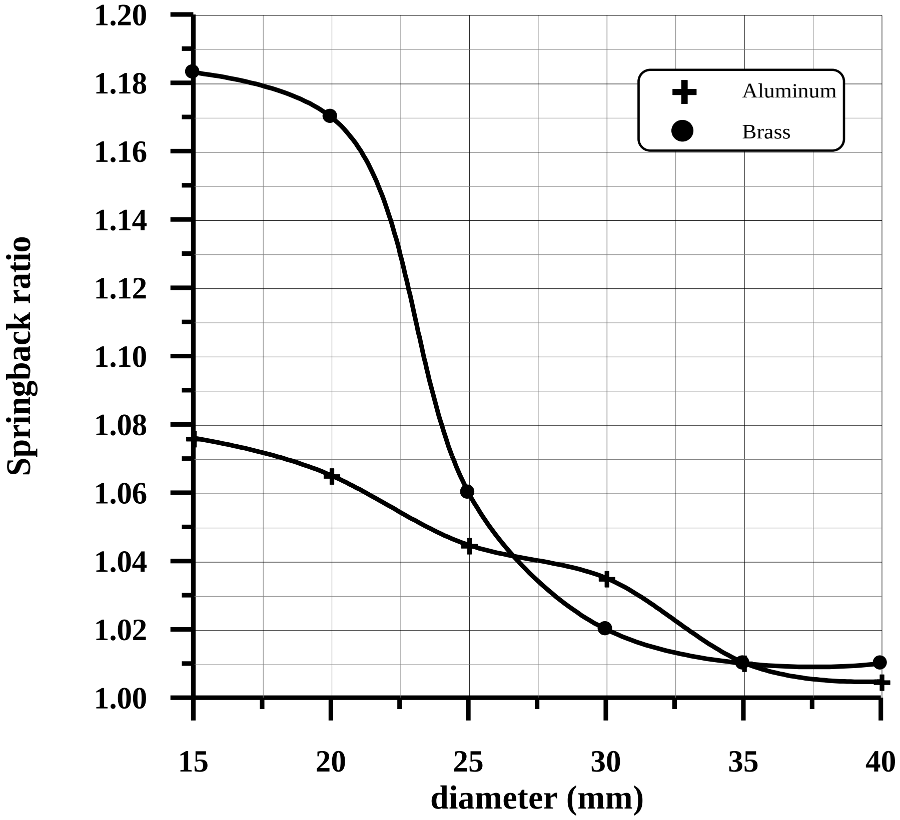


Fig. (13): Springback ratio versus diameter of disk.

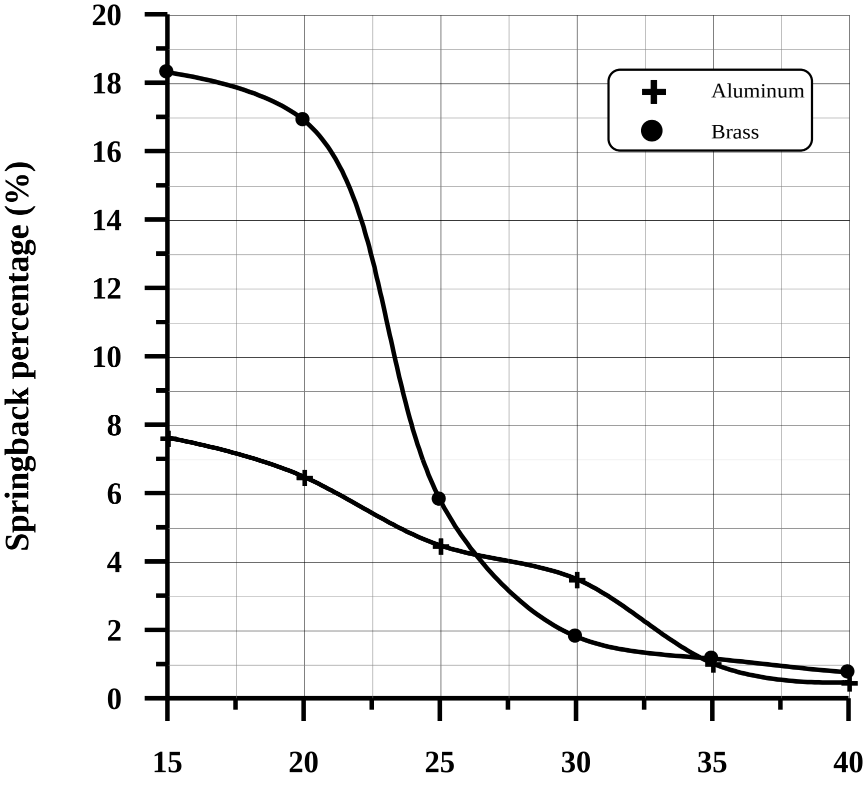


Fig. (14): Springback percentages versus diameter of disk

قَابلِيَةُ تَشكِيلِ الصفائح بِاستخدامِ ضاغط نِصفِ كروي و قالب مطاطي

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الخلاصة:

في السنوات الاخيرة، حقق استخدام المواد المطاطية مقبولية كوسط لنقل الضغط في مختلف فعاليات تشكيل المعادن بسبب التطورات التي واجهتها هذه الصناعة و المرونة التي يحققها المطاط لها.

الغرض من هذا البحث هو دراسة قابلية تشكيل الصفائح باستخدام قالب قابل للانضغاط مصنوع من المطاط الطبيعي. عملية التشكيل جرت باستخدام كرة فولاذية كقالب نصف كروي. تم اجراء اختبار الشد لمعرفة الخوص الميكانيكية لمواد الصفائح المشكلي والتي هي الالمنيوم و البراص. تم بعد ذلك اجراء اختبارات تشكيل الصفائح وبسمك ٠.٥ ملم لانتاج اطباق باقطار مختلفة (١٥– ٤٠ ملم). رسم لعملية التشكيل مخطط القوة–الشوط لقياس شدة الطبق اثناء التشكيل و فيما بعد لدراسة و مقارنة العوامل المؤثرة و المصاحبة له. تم تقيم المرونة الارجاعية (springback) و الانبعاج المحيطي (wrinkling) المصاحب لعملية التشكيل. وجد من خلال تحليل النتائج ان شدة الطبق المشكل تزداد بزيادة قطره وصولا الى قيمة يظهر فيها الانبعاج المحيطي وعندها يبدأ بالنقصان فوق قيم ذلك القطر(قطر ٣٣ ملم لطبق الالمنيوم و ٢٨ ملم لطبق البراص). وجد ايضا ان المرونة الارجاعية للاطباق المشكلة تزداد مع زيادة قطر الاطباق حتى يظهر الانبعاج الجانبي، وان قيم المرونة الارجاعية للالمنيوم اكبر منها للبراص.

الكلمات المفتاحية: إمكانية تشكيل الصفائح، المرونة الارجاعية، الانبعاج المحيطي، القوالب المطاطية، إمكانية التشكيل.