# Fabrication of aluminum bipolar plates using multi-stamping wire with various shapes by rubber pad forming process

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## Abstract

The rubber pad forming process used for the production of bipolar plate (the heat exchanger). The parts needed for the rubber pad forming consisted form mold (male which represent the upper die or punch, and female which represent the lower die or container), stamp or metal wire, sheet plate, rubber and compressor. The geometry of the created part (channels) follows the geometry of the stamp (metal wire) in sheet metal forming procedures. When the steel mold descends, it touches the stamp (wire designed to form the heat exchanger) and pressure is applied to it. The pressure is transmitted to the sheet in contact with the rubber to deform the rubber in an elastic fashion, creating a counter-pressure. Due to the counter pressure, both the rubber and the vacuum flow into the rigid mold chamber at the same time. This mold consists from two parts. The first part (female) with inner diameter of 8 cm and an outer diameter of 13 cm with height equal to 13 cm. The second part (male) with diameter 8 cm and height equal to 8 cm connected to the head with diameter 10 cm and thickness equal to 1 cm. A circular sample of aluminum with a diameter of 8 cm and a thickness of 0.5 mm. Wire of various diameters, shapes and metals were used for the process of forming the heat exchanger. The wire used in the forming process consists of different metals alloy of (aluminum, brass and zinc) and copper. Problems such as wrinkling has been noticed during the forming process. The process of forming the stamp is easy and inexpensive and does not require complicated tools and devices for the forming process, but it requires simple equipment and this leads to less cost, speed and time, and does not require any experience. As the hardness of the metal increases, the displacement increases and the strength required for the forming process decreases.

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## 1-Introduction

The elastomer forming technology has gained popularity on the shop floor in recent years, and it is increasingly being used as a pressure-transmitting medium for various metal-forming procedures. This is mostly owing to the development of new materials and tooling techniques, both of which have piqued corporate interest in the process.[1]

Several novel sheet metals forming methods have been introduced in recent decades. Unconventional tools such as fluid, gas, viscous medium, and elastomer pads as pressure carrying agents are one of the categories of these creative procedures. In recent years, these adaptable tools have become more prevalent in the design of metal forming processes. [2]

The geometry of the created part follows the geometry of the die in sheet metal forming procedures.[2]

Due to the rubber pad has a low hardness, the sheet metal suffers less wear when compared to deep drawing. The rubber's ability to exert pressure is limited due to its own strength. [2]

The use of flexible-die forming (FDF) technology to replace metallic tools has shown to be an effective means of cutting lowering the cost of initial tooling and streamlining the forming process. In addition to the stiff steel tooling that was previously employed, these adaptive tools are now being used.[3]

Rubber forming requires only a single metallic punch and a rubber pad encased in a rigid box to operate as a die. The elastomer's incompressibility is employed to apply hydrostatic pressure to the sheet metal by deforming it at a constant volume. [4]

The rubber operates like a hydraulic fluid as the punch goes surrounding the punch or form block, delivering roughly equal pressure to all workpiece surfaces.[5]

Sheet metal formability in sheet flexible-die forming is greatly influenced by the qualities of the pressure-transmitting medium.[6]

During the forming process, these soft materials are utilized to eliminate surface blemishes from the sheet. When compared to traditional forming, flexible rubber forming has numerous advantages.[7]



Rubber forming helps speed up the forming process, reduce springback and improve surface quality while reducing manufacturing preparation time. [8][9]

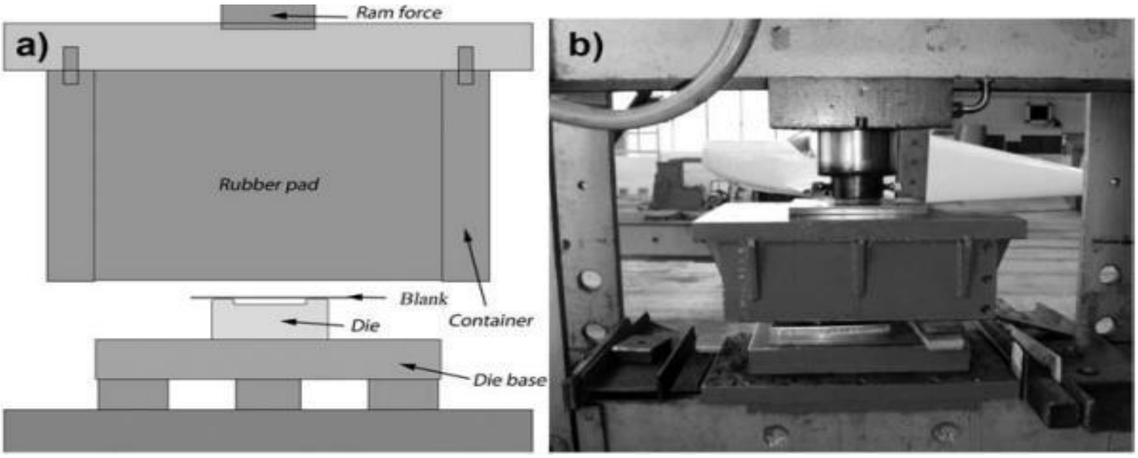


**Fig [A]** a) A rubber-pad forming process is depicted schematically; b) An experimental tool set-up is shown. [10]

Some of the advantages of employing a rubber-pad forming procedure rather than standard metallic tools are as follows (1) because a rubber pad may return to its original shape, it can be utilized to make a variety of workpiece forms using the same flexible pad; (2) traditional forming procedures have higher tool costs; (3) The amount of work metal thinning that happens during traditional deep drawing is greatly reduced; (4) set-up time is significantly reduced. (5) because no tool marks are generated, no lubrication is required, and an excellent surface polish can be achieved. However, the rubber-pad forming processes have several drawbacks, including:(1) I a flexible pad's lifetime is limited (this is determined by the severity of the forming as well as the pressure applied.); (2) pieces with lesser sharpness or wrinkles occur from insufficient forming pressure, necessitating reworking of the parts to their precise shape and dimensions; and (3) because of their poor production rate, they are only appropriate for small series; (typical of the aircraft industry).[11][12][ 3]

Despite its lengthy history and adaptability, the technology has yet to be fully adopted by industry. This is due in part to a lack of understanding of the process variables, and in part to manufacturers' aversion to replacing a well-functioning and amortized facility. It is hoped that industry would notice the significant contribution that the method may make in the near future. There are numerous works that deal with rubber formation, such as tire forming.[13]

**2-Experimental work**

The metal forming process depends on the basic parts (rubber, mold, stamping, sheet plate and press) to obtain the heat exchanger.

When the steel mold descends, it touches the stamp (wire designed to form the heat exchanger) and pressure is applied to it. The pressure is transmitted to the sheet in contact with the rubber to deform the rubber in an elastic fashion, creating a counter-pressure. Due to the counter pressure, both the rubber and the vacuum flow into the rigid mold chamber at the same time. The manufacturing process is done using the anti-pressure of the rubber pad to bring the void to the bottom of the steel mold, then filling of the voids carried out until they fit tightly inside the steel mold metal forming entails changing the shape of metals in a controlled manner.

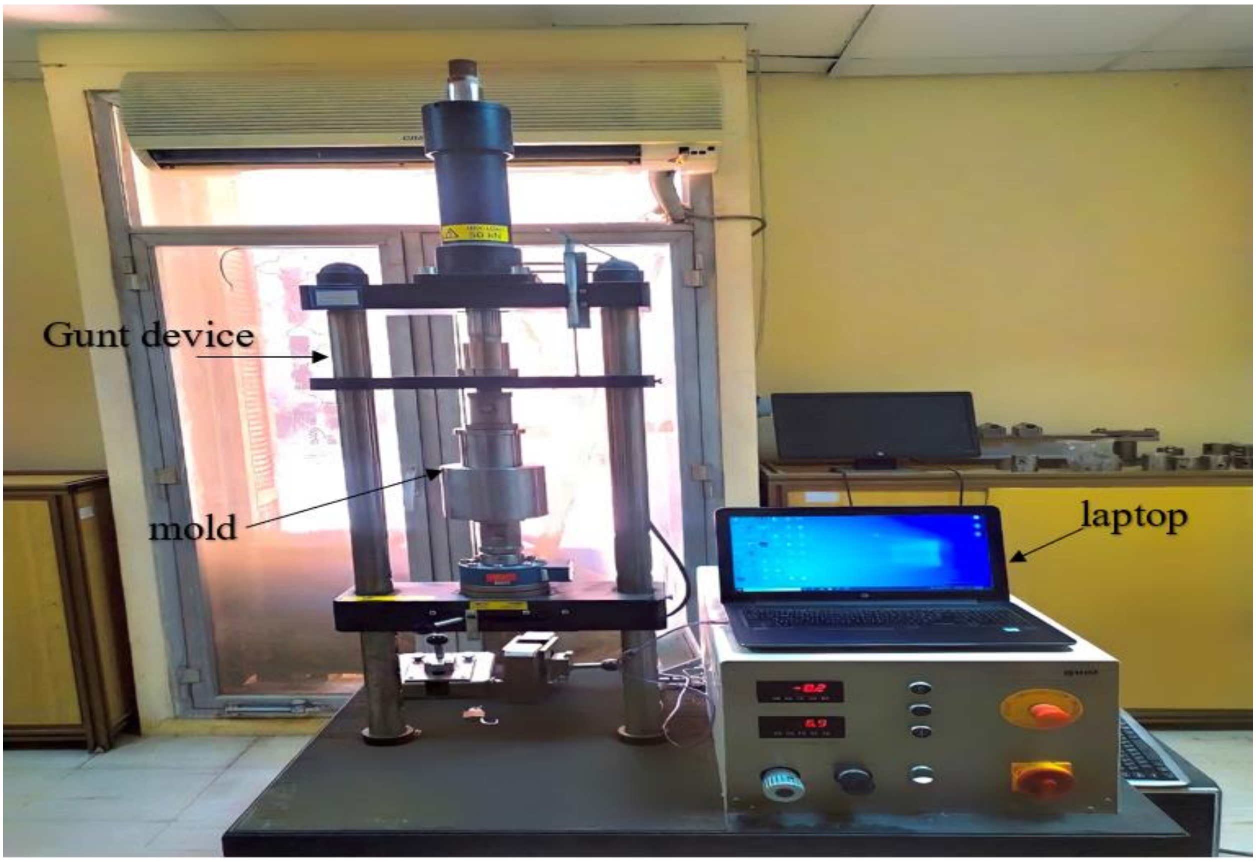


**Fig (1):** workshop parts which consist from (laptop, mold, gunt device, stamp, sheet plate and rubber).

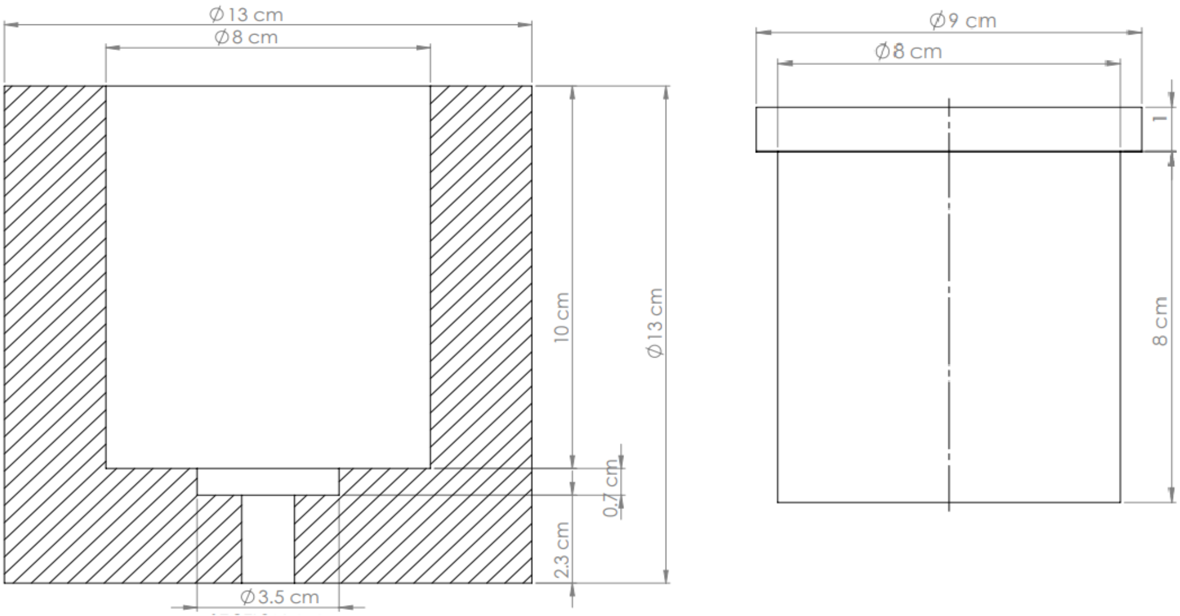


**Fig (2):** scheme shows the dimensions of the mold.

## 2.1 Material of stamping

Four wires of different metals were used in the molding process. The mold is used to form the heat exchanger.

### 2.1.1 Chemical Composition of stamping

The first wire, a motorcycle wire was used in the mold forming process, and the metal was examined using the test technique (XRF) and the results of the examination were obtained in the table (1) below. Whereas the results obtained in the test were compared with the specifications of the American Society for Testing of Materials (ASTM) that the metal has its chemical symbol zinc-iron alloy (ZF180).



| symbol | Cr% | Mn% | Co% | Cu% | Mo% | Ni% | S% | Fe% | Zn% |
|---|---|---|---|---|---|---|---|---|---|
| | 0.1579 | 0.1022 | 0.1967 | 0.5208 | 0.068 | 0.0888 | 0.031 | 12.5 | 85.30 |

**Table (1):** Chemical Composition of zinc alloy

The second wire was welding aluminum is mostly used to weld aluminum alloys. the metal was examined in the same center and the device above. The chemical composition of the metal was obtained and shown in the attached table below (2). And the result was compared with the results of the examination with the American Standard (ASTM) where the metal falls within the specification (SFA 5.10 (ER 4043) ($ALSI_5$).

| symbol | Mg% | Si% | Fe% | Mo% | Zn5 | Cu% | Ni% | Co% | Al% |
|---|---|---|---|---|---|---|---|---|---|
| | 1.71 | 7.07 | 4.76 | 1.32 | 0.749 | 2.484 | 0.407 | 0.195 | 80.12 |

**Table (2):** Chemical Composition of aluminum.

The other wire was a yellow copper (brass) welding wire is mostly used to weld copper alloys was used for the process of forming the mold, where the wire was examined in the same center and the above device. The results were obtained and shown in the table below (3). The results that we obtained in the examination process were compared with the American Standard (ASTM) where we found the metal falls within the specification (UNS c26800).

| symbol | Al% | Si% | Cr% | Cd% | Mo% | Ni% | Fe% | Zn% | Cu% |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0342 | 0.0133 | 0.0677 | 0.198 | 0.117 | 0.071 | 0.0672 | 33.50 | 64.84 |

**Table (3):** Chemical Composition of yellow copper (brass).

The last wire used in the mold forming process was a copper wire. The wire was examined in the same center and the above device, and the chemical composition was obtained as in the table below(4). The obtained metal is near to pure copper

| symbol | Ti% | Ni% | Cr% | Mn% | Fe% | Co% | Mo% | P% | Cu% |
|---|---|---|---|---|---|---|---|---|---|
| | 1.098 | 0.123 | 0.0596 | 0.05 | 0.0571 | 0.0415 | 0.054 | 0.0062 | 97.47 |

**Table (4):** Chemical Composition of copper alloy.

### 2.2 Hardness test

The hardness test is a testing process for properties of materials which can be used in design process, assessment of constructions, and materials development. The sample was examined for the zinc alloy, copper alloy, copper alloy (brass) and aluminum alloy, material Vickers measurement rate ranging between (240-290) HV, (110-135) HV, (120-170) HV and (95-112) HV was obtained Respectively.

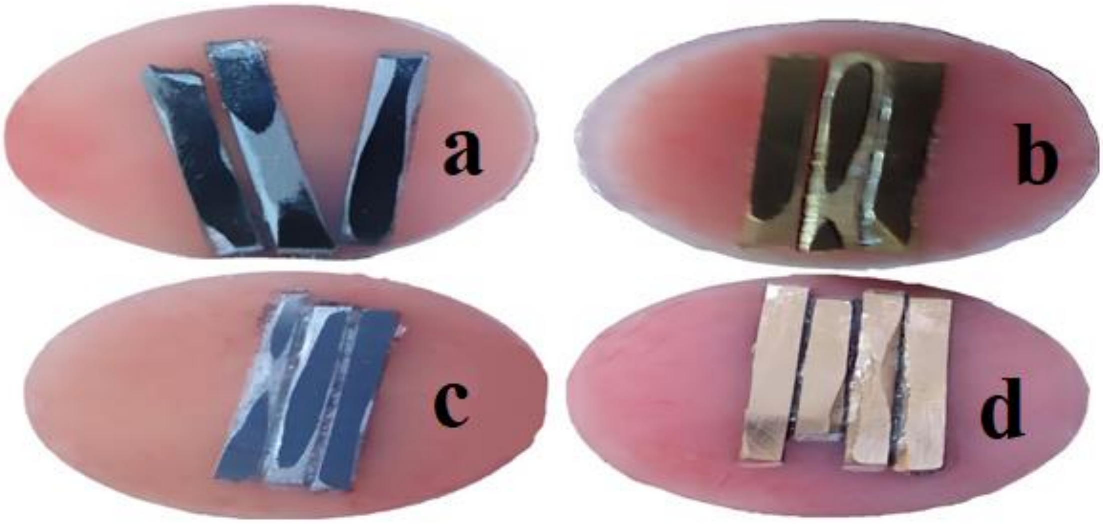


**Fig (2):** the examined samples: **a)** zinc alloy **b)** brass **c)** aluminum alloy **d)** copper.

### 2.3 Design stamping:

Wire of various diameters, shapes and metals were used for the process of forming the heat exchanger. Furthermore, the shaping process was done with simple tools to reach the desired shape. The wire used in the forming process consists of different metals alloy of (aluminum, brass and zinc) and copper. Wires of various diameters were used ( 2.8mm, 3mm and 3.5mm ). The metals used in the forming process differ from one material to another in the forming process, where copper metal can form various shapes easily because it is easy to fold and formable, so we can reach the desired shape accurately and also can form a sharp angle (90 degree) without being subjected to the fracture process and this is what distinguishes it from the rest of the alloy metals that were used in this search. As for the aluminum alloy, it is easy to form, Shapes with sharp corners and to a lesser degree can be obtained from copper. As for the brass, it is difficult to obtain accurate dimensions, as well as obtaining shapes with sharp angles, because it is subjected to fracture. The last metal used in the forming process in this research is alloy of zinc, where zinc has strength compared to the rest of the metals used, but it is difficult to form and obtain accurate dimensions using simple tools

The wires formed in different and basic shapes were adopted and were used in all formation tests. Each shape was encoded on a specific letter to signify, where a similar shape was made to the symbol (∩) and this basic shape was applied to the four wires used as in the figures (3) where the diameter of the arch **(∩)** is diameter 3cm. We noted that the shapes are different with the accuracy of the arch shape. The arch is inaccurate due to the difficulty of obtaining a regular shape for this alloy. As for the brass, we also note that the arch is inaccurate, but to a better degree than zinc because of the better formability of brass. As for copper and aluminum alloy, we notice the arch is more accurate because it is easier to form these two wires.

Finally, different shapes of the copper wire were designed. The first shape is referred to with the symbol (∩) and the second shape it was encoded in the samples with the symbol (U) as in the figure (4d). The third shape was encoded by the symbol (O) as in the figure (4b). The fourth shape, which resembles a Christmas tree, as in the figure (4c). And the last shape used, as in figure (4a).

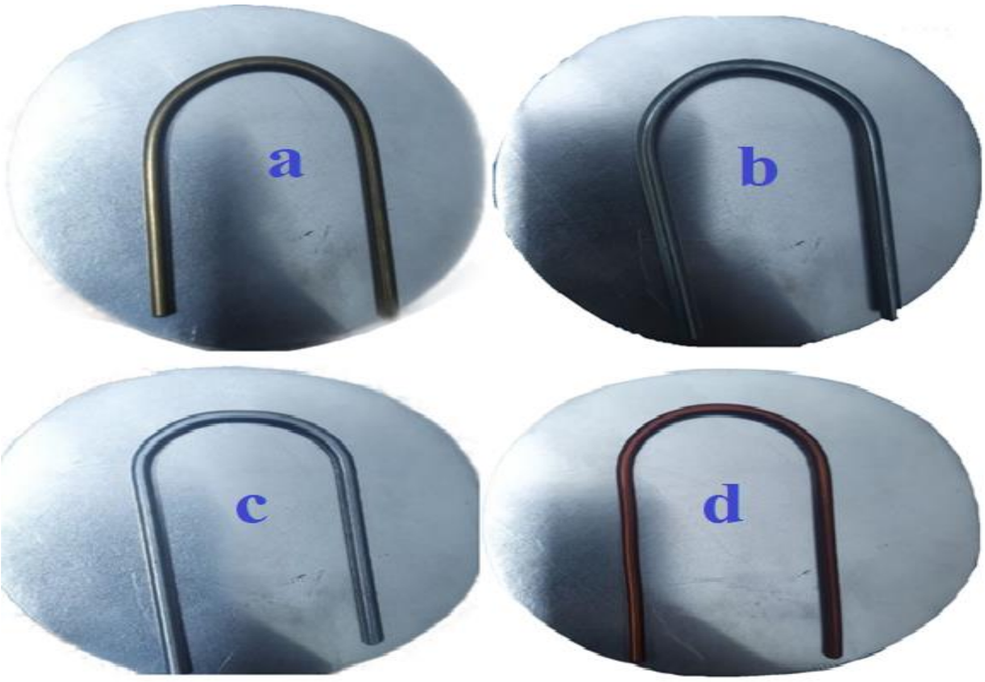


**Fig (3):** stamping designs of **a)** brass **b)** zinc alloy **c)** aluminum alloy **d)** copper.

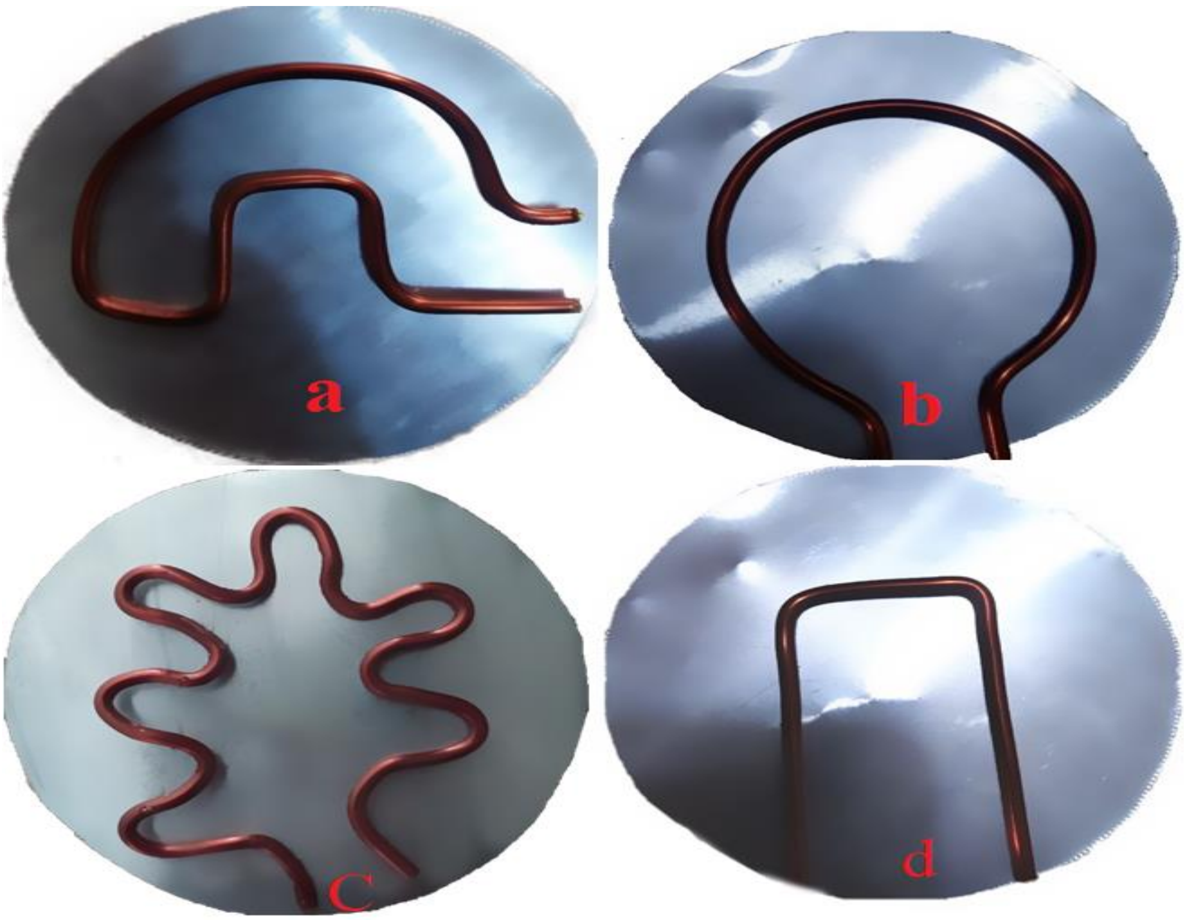


**Fig (4):** stamping designs of copper.

The resulted shapes range from simple to complex designs with different angles, these various shapes were used to show the ease of forming these metals. Any possible shape can be obtained quickly with copper by simple equipment's.

## 3. Results and Discussions

### 3.1 Forming bipolar:

Bipolar wires were used to form different shapes depending on stamping. When using the aluminum alloy wire, the shape as in the figure (5a) was obtained, we notice from the figure the resulting sample symbols, where each symbol indicates an information, as the first part denotes the type of metal used, and the second part denotes the type of rubber used, where (R1) denotes natural rubber, (R2) denotes sponge rubber, and (t) denotes the thickness of the rubber used, and (sp) indicates the speed, as three speeds were used in the research (3,5,7)mm/s and when using the zinc alloy wire, we get the shape as in the figure (5b), and when using the brass wire, we get the shape as in the figure (5d) and finally more than one stamping of the copper alloy was used to obtain different forms, as in the figures (5c and6). The bipolar forming process is by merging two pieces of samples produced during the forming process and they are poured to obtain a stream, as the first piece resulting from the molding by stamp and the second piece, we get during the turning of the stamping as in the figure (8), (7)


**Fig (5):** bipolar forming process.

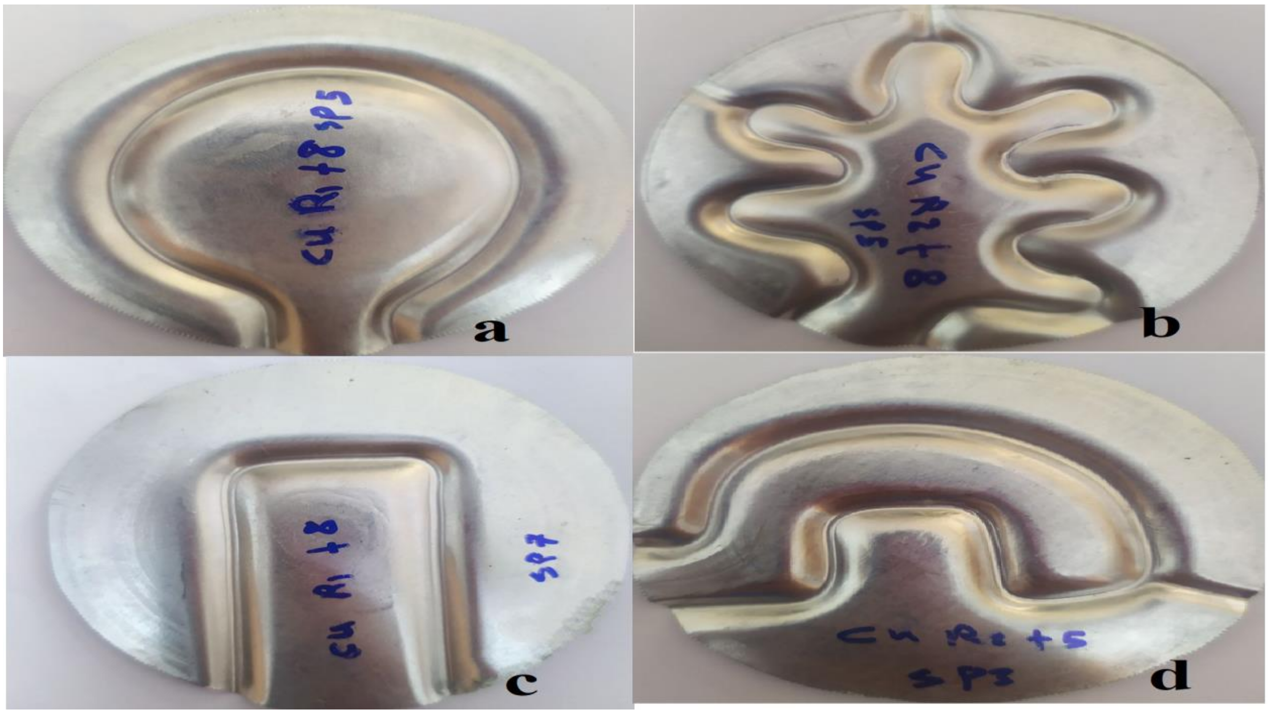


**Fig (6):** forming of bipolar by using wire alloy copper.

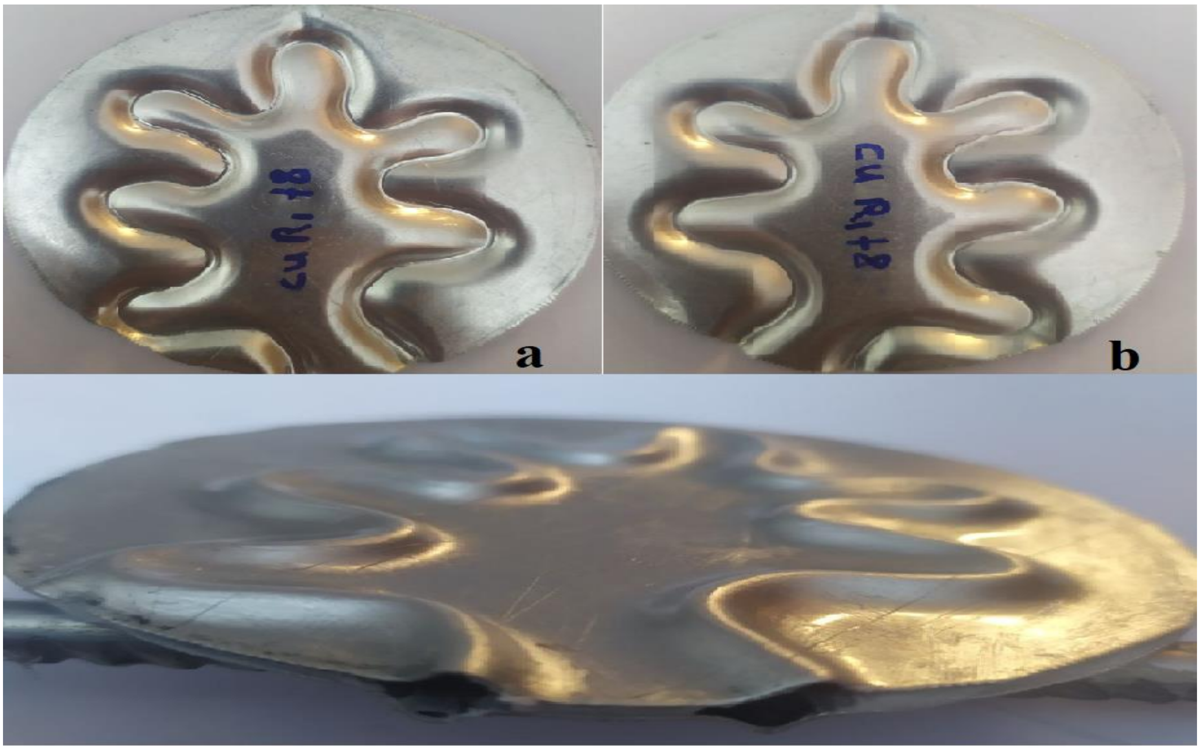


**Fig (7):** (a) the first sheet plate. (b) the second sheet plate.
(c) combination of the two sheet plates.

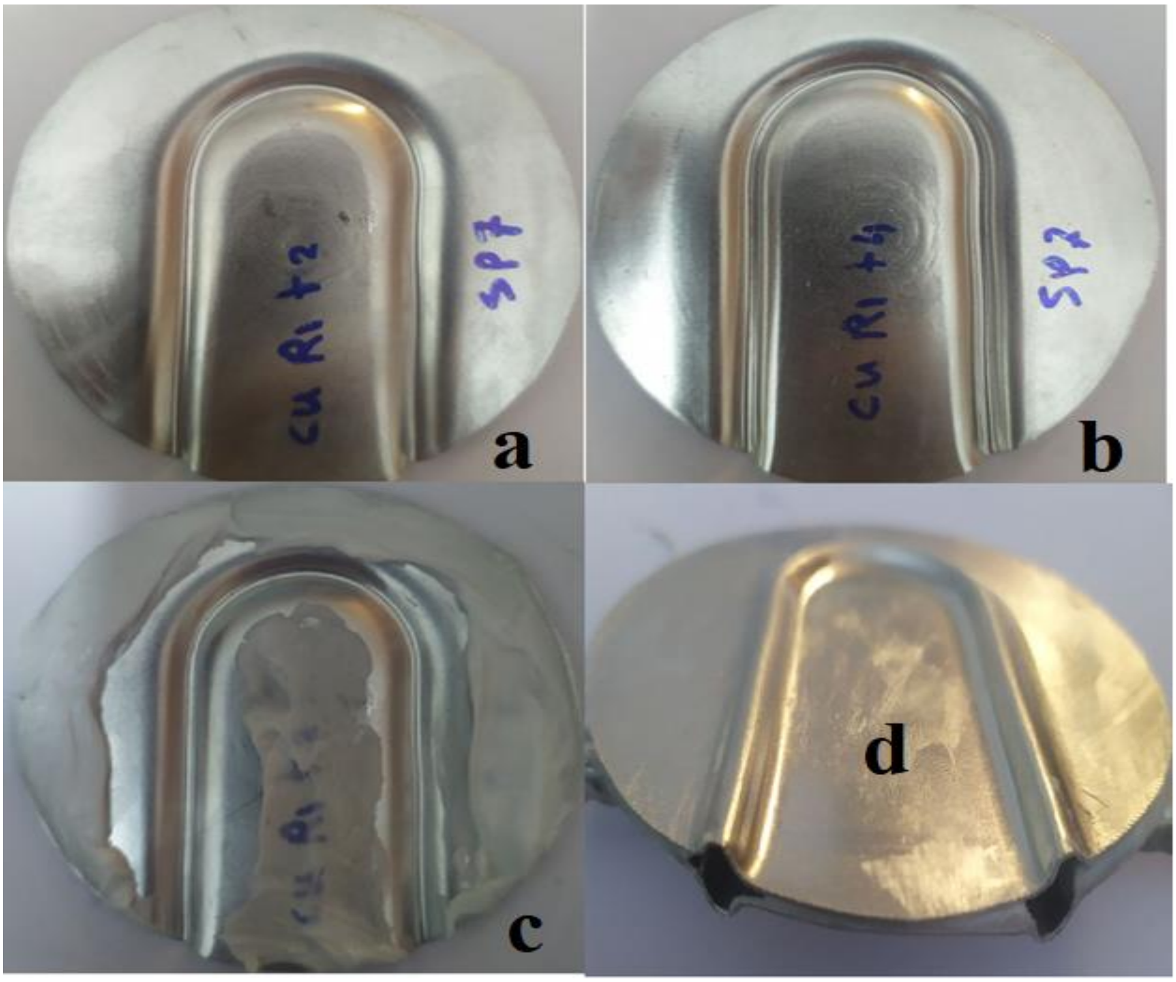


**Fig (8):** (a) the first sheet plate. (b) the second sheet plate.

(c) silicone glue dispersion over the first plate.

(d) the combination of the two sheet plates.

## 3.2 Various wires of stamping

### 3.2.1 Natural Rubber

Different wires (brass, aluminum alloy, copper alloy and zinc alloy) and natural rubber 8 cm thick at speed (3mm/s) were used in the process of forming the heat exchanger. Where the results obtained in the same conditions vary from one wire to another. We noticed that during the forming process using aluminum alloy wire, it needs the highest strength compared to the rest of the wires used in forming. In the case of the stability of the force used(50KN), we note that lowest displacement can be obtained and then comes the copper wire, where the displacement is higher compared to the aluminum alloy by 1.77 %, as well as the stability of the strength value, and then the copper alloy wire (brass), where the displacement is higher compared to aluminum alloy by 3.06 % as shown in force-displacement diagram (1). Finally, the zinc alloy wire, where we note that it is the highest displacement, and when compared to aluminum alloy it has a higher displacement by 4.67 % that can be obtained during forming in the same previous conditions. When comparing the hardness of the metals, the hardness of the zinc wire is harder than the rest of the wires. As the hardness of metal wire increased the full pressure transferred to the sheet plate is also increased and the applied force needed for the forming process is less.

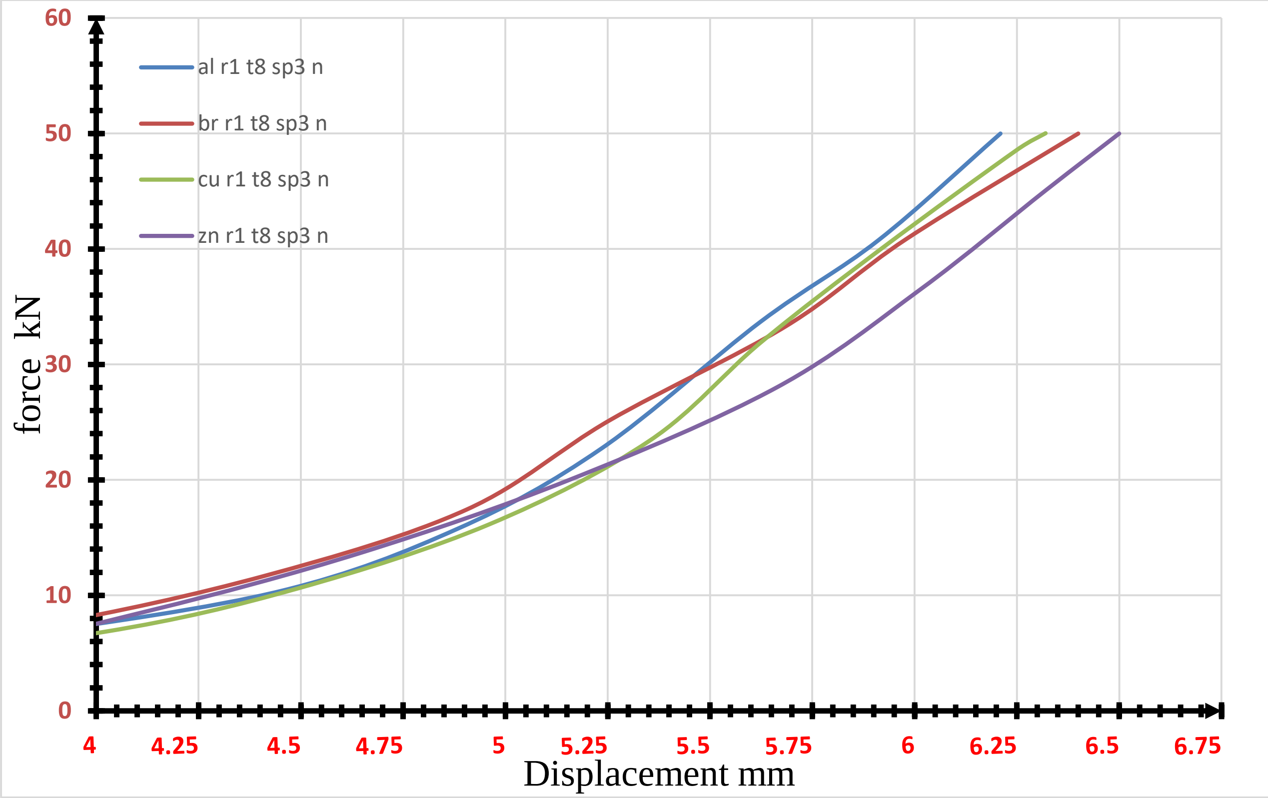


**Diagram (1):** force-displacement diagram for different wire when using natural rubber.

### 3.2.2 Sponge Rubber

Different wires (brass, aluminum alloy, copper and zinc alloy) and sponge rubber 8cm thick at speed (3mm/s) were used in the process of forming the heat exchanger. The results obtained in the same previous conditions, where we notice that as in the diagram (2). When the applied force is 50 KN, aluminum was noticed to has the lowest displacement. Copper, brass, and zinc have a higher displacement by percent (2.4, 5.6, and 12 %) respectively when compared to aluminum alloy. Where we note that the highest displacement that can be obtained with a constant value of the wire force is the zinc alloy wire, and the lowest value is the aluminum alloy, and the copper alloy (Brass) and the copper are located in the middle. The reason for the results obtained is that the hardness of the zinc alloy is more than that of other wires.

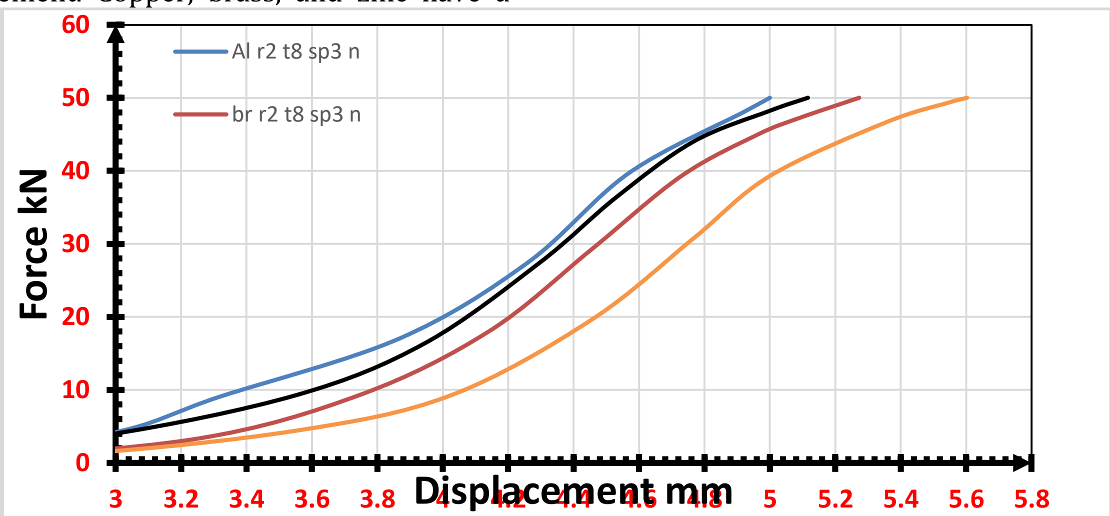


**Diagram (2):** force-displacement diagram for different wire when using sponge rubber.

### 3.3 Size of stamping:

The size of the stamp is very important in the shaping process, as the dimensions of stamp should be less than the dimensions of the sheet, and the corners of the stamp should be at an appropriate distance so that there are no wrinkled edges and to get a regular shape. In this research, a circular-shaped sheet plate was used, so the shapes used it has arches to avoid wrinkling. At the beginning of the research, a shape with 90-degree angle and a large size of stamp was used, as in the figure (9) during the formation process, a shape with wrinkled edges has been noted and this resulting shape is useless in the forming process. So that to make a certain shape without wrinkling or wrinkled edges, the sheet plate should be larger than the stamp but to certain degree

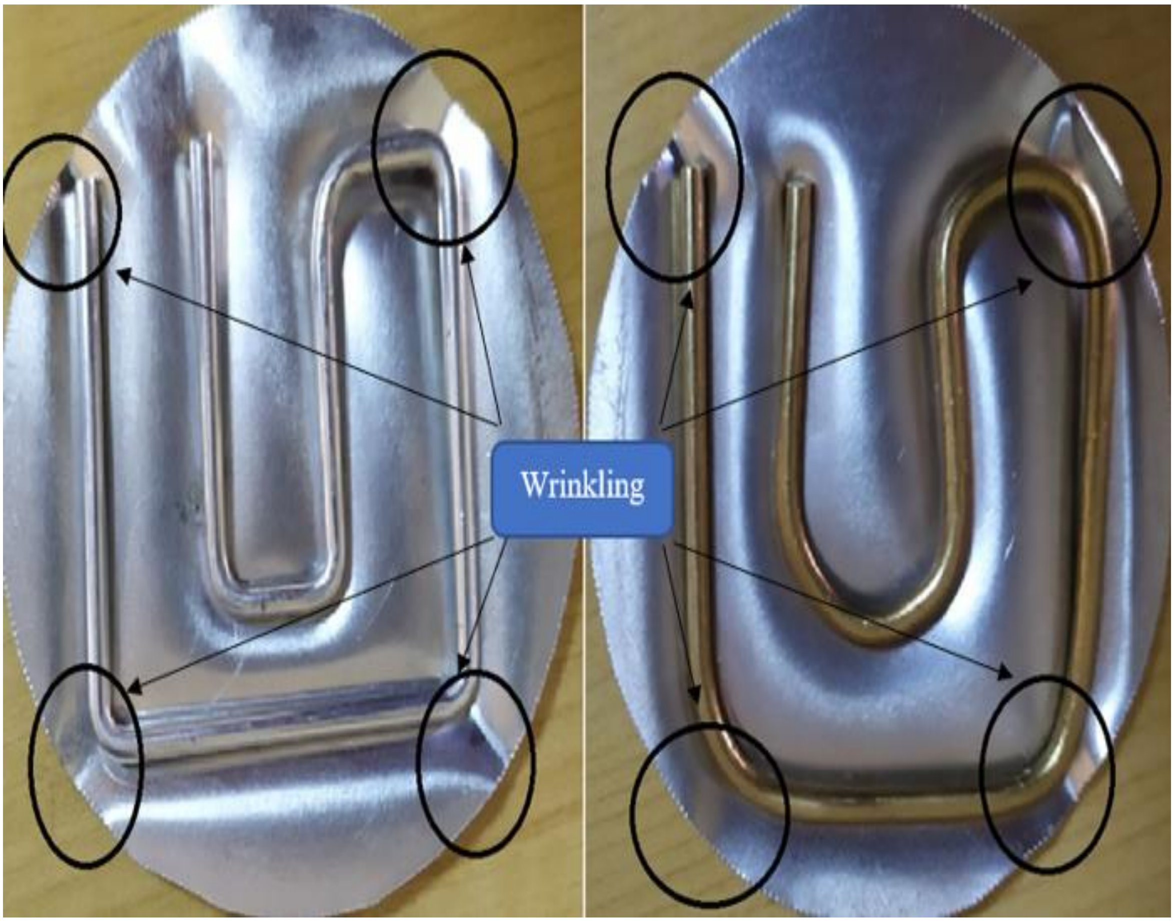


**Fig (9)** a large size of stamp and wrinkling at the corner

### 4. Conclusion

1- The process of forming the stamp is easy and inexpensive and does not require complicated tools and devices for the forming process, but it requires simple equipment and this leads to less cost, speed and time, and does not require any experience.

2- Rubber can be used in the forming process even if it is subjected to fatigue with similar results because rubber remains a stress carrier.

3- copper is the preferred metal used in the process of forming the stamp, because of easy forming process compared with other metals, does not affected by multiple forming process and it is available in abundance.

4- Zinc alloy got the best results as it needs a lower forming strength compared to the rest of the metals used in this research, but it is difficult in the process of forming the stamp.

5- Despite the ease of forming process in case of using aluminum, we noticed after a number of forming tests that the stamp was subjected to deformation and needed higher pressures for the forming process.

6- As the hardness of the metal increases, the displacement increases and the strength required for the forming process decreases

7- The wrinkling is formed at the edges of the sheet plate, and if the stamping is relatively large compared to the sheet plate.

**Reference: -**


1- Al Hilli, A. H. M. (2010). Sheet Formability Using Hemi-Spherical Punch And Rubber Die. *AJES*, *3*(2), 58.

2- Perrella, F. W., & Gaspari, A. A. (2002). Natural rubber latex protein reduction with an emphasis on enzyme treatment. *Methods*, *27*(1), 77-86.

3- Ramezani, M., & Ripin, Z. M. (2012). *Rubber-pad forming processes: Technology and applications*. Elsevier.

4- Thiruvarudchelvan, S. (1993). Elastomers in metal forming: a review. *Journal of Materials Processing Technology*, *39*(1-2), 55-82.

5- Battikha, E., & Browne, D. J. (1992, September). Experimental rubber-pad forming of aluminium sheet. In *Proc. 9th Conf. Irish Manufacturing Committee* (pp. 479-487).

6- Yuan, B., Fang, W., Li, J., Qu, Z., Cai, Y., & Wang, Z. (2016). Effects of viscosity on viscous pressure bulging (VPB) of Al1060 sheet. *The International Journal of Advanced Manufacturing Technology*, *86*(1), 215-225.

7- Belhassen, L., Koubaa, S., Wali, M., & Dammak, F. (2016). Numerical prediction of springback and ductile damage in rubber-pad forming process of aluminum sheet metal. International Journal of Mechanical Sciences, 117, 218-226.

8- Belhassen, L., Koubaa, S., Wali, M., & Dammak, F. (2016). Numerical prediction of springback and ductile damage in rubber-pad forming process of aluminum sheet metal. International Journal of Mechanical Sciences, 117, 218-226.

9- Ramezani, M., Ripin, Z. M., & Ahmad, R. (2009). Computer aided modelling of friction in rubber-pad forming process. Journal of Materials Processing Technology, 209(10), 4925-4934.

10- GUME, P. Z. V. I. (2012). Computer-aided modeling of the rubber-pad forming process. Materiali in tehnologije, 46(5), 503-510.

11- Ramezani, M., & Ripin, Z. M. (2012). Principles of rubber-pad forming. Rubber-pad forming processes technology and applications. Cambridge: Woodhead Publishing, 23-42.

12- Belway, B. P. (2006). ASM Handbook, vol. 14B—Metalworking: Sheet Forming. ASM International, 367-374.