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The Effect of the Solution Heat Treatment on the Mechanical Properties of Aluminum-Copper Alloy (2024-T3) Using Rolling Process

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Abstract

The effect of solution heat treatment on the mechanical properties of Aluminum-Copper alloy. (2024-T3) by the rolling process is investigated. The solution heat treatment was implemented by heating the sheets to 480 C° and quenching them by water; then forming by rolling for many passes. And then natural aging is done for one month. Mechanical properties (tensile strength and hardness) are evaluated and the results are compared with the metal without treatment during the rolling process. ANSYS analysis is used to show the stresses distribution in the sheet during the rolling process. It has been seen that good mechanical properties are evident in the alloy without heat treatment due to the strain hardening and also the mechanical properties are improved after heat treatment and rolling process but with lower forces and stresses when compared with the untreated.

Keywords: *Forming process, rolling, heat treatment, ANSYS.*

1. Introduction

The ability to use the rolling processin different industries purposes depends on whether the metal is ferrous or non ferrous. This is because of the different mechanical properties, e.g., strength, ability of plastic forming and physical properties like thermal, electrical and magnetic conductivities. From the important things for choosing the suitable metal for production is having confined chemical construction and good ability for plastic forming in order to take the desired form without changing the chemical instruction of metal experimentally. Due to the ability of plastic forming of metal by applying confined force related with the volume and shape of the product, the procedures are various depending on the way of applying the force; these procedures are: rolling, dragging, extrusion, bending and shearing. Wang (2009), studied the alloy (Al–10.8Zn–2.8Mg–1.9Cu) synthesized by the spray atomization and deposition technique. Microstructure and mechanical properties of the spray-deposited alloy processed through hot rolling and heat treatment were investigated by means of scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction and tensile test. The results indicate that the microstructure of the spray-deposited alloy is mainly composed of the Al matrix and the $Mg(ZnCu)_2$ compounds. The fragmentation of the $Mg(ZnCu)_2$ phases in the alloy has been regarded as one of the main feature during hot rolling. After solution treating, the microstructure is found to be composed of the Al matrix and a spot of Al_7Cu_2Fe, Al_9FeNi compounds. The spray-deposited Al–Zn–Mg–Cu alloy in the T6 temper displays superior strength due to the presence of two types of coherent GP zones (spherical GPI zones and thin platelet GPII zones). Shahani et al, (2009), parametrically studied hot rolling process by the finite element method of AA5083 aluminum alloy. Chandramohan et al (2009) made a review for of rolling process with ohsas and texture formation.

This study investigates the effect of solution heat treatment on the mechanical properties using rolling process is.

2. Calculating the Force and Energy Required for Rolling Process

The required force for rolling in simple rolling mechanism with two rollers could be calculated as shown in Fig. (1) by equation (Nagpal,1998) :

$$F_r = L\ W\ \sigma\ Q_P \qquad \ldots(1)$$

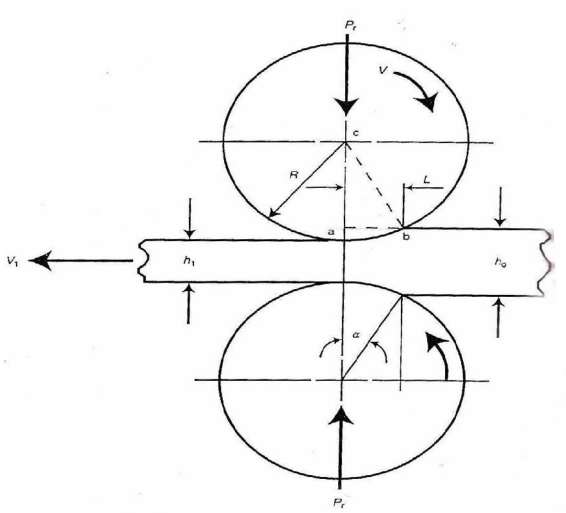

Fig.1. Dimensions of Rolling Process.

From Fig.(1), it is seen that the output speed is greater than the input speed for the constant speed of rollers and there is one point of contact angle (α) in case of the sheet and rollers moves in the same speed. Due to this process the friction force affects at the neutral point therefore it is important for rolling which cause to reduce the energy from the rollers caused forming. If the friction coefficient of roller approaches to zero, the roller will slide on sheet, the means no forming will be done, so that the lubrication must be controlled during the rolling process to prevent skidding (Johnson and Needham,1982) .

The force during the rolling process could be calculated related to the contact line measured from equation (2).

$$L = \sqrt{R}(h_o - h_i) \qquad \ldots(2)$$

In the case of (h/L<1), the roller diameter is bigger when compared with the sheet thickness and the plastic deformation will be plane strain case and homogeneously and the rolling pressure can be determined from

$$P_r = \sigma_{tm}\ Q_P \qquad \ldots(3)$$

Hence, the force is equal to

$$F_r = L\ w\ \sigma_{tm}\ Q_P \qquad \ldots(4)$$

In spite of that the length increases along the rolling but the width will be constant if (w/h>10) is for the most rolling processes.
From equation (4) it is seen that the decrease in contact length (L) by decreasing the radius of roller made the required force decrease .

In case of (h/L>1) which means that the sheet thickness is bigger when compared with roller radius therefore the non homogeneous forming occurrs, because of sticking which is undesired, but it happens in rolling process for big blocks, and pressure could be obtained in this case by(Johson and Miller,1973);

$$P_r = \sigma_{tm}\ Q_i \qquad \ldots(5)$$

The non homogeneous deformation could cause cracking defect in the condition of;

$$\frac{h_o}{R} > \left(\frac{h_o}{h_i} - 1\right) * 1.18 \qquad \ldots(6)$$

The torque of roller obtained from

$$T = F_r\ L \qquad \ldots(7)$$

The roller power could be determined by;

$$Power = \omega\ T \qquad \ldots(8)$$

where ω is the angular velocity determined from;

$$\omega = V / R \qquad \ldots(9)$$

3. Experimental Part

3.1. Alloy Selection

Aluminum alloy (2024-T3) had been selected treatable because an employment in many engineering applications such as air transmission structures. To check up the chemical instruction of metal alloy, chemical analysis had been done by spectrometer and the results explained in table(1).

Table 1,
Chemical Instruction for Aluminum Alloy (2024-T3).

Element	Al	Ti	Cr	Zn	Si	Fe	Mn	Mg	Cu
Real Value	92.6	0	0.05	0.1	0.4	0.3	0.6	1.5	4.4
Standard Value		0-0.15	0-0.1	0-0.25	0-0.5	0-0.5	0.30-0.9	1.2-1.8	3.8-4.9

However the mechanical properties illustrated in table(2), where the available alloy sheet was formed as a plate having 10mm thickness to be suitable for deferent conditions research like making rolling processes experiments in deferent rates.

Table 2,
Mechanical Properties of Aluminum Alloy (2024-T3).

σ_y MPa (proof stress 0.2%)	σ_U MPa	Elongation EL.%	ρ (Kg/m^3)
414	483	10%	2800

3.2. Preparing Sheets for Rolling

The dimension of the rolling sheet is shown in Fig.(2).

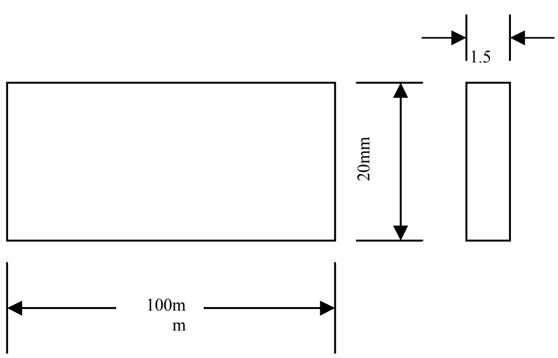

Fig.2. Specimen Dimensions.

Table 3,
Classification of Used Sheets.

Case	Specimen symbol
The basic material	A
Rolled without heat treatment	B
Rolled to 1.4mm	B1
Rolled to 1.275mm	B2
Rolled to 1.2mm	B3
Rolled to 1.1mm	B4
Solution treatment before rolling	C

3.3. Classification of Sheets

After cutting the sheets they had been classified into groups shown in table (3).

4. Heat Treatment Solution

Solution heat treatment had been done for sheets (type C) where the sheets are heated to 480 C° temperature then cooled quickly (quenching) by water.

5. Rolling Process

Rolling process had been done for sheets (types B & C) from table (3) by rolling machine has two rollers of 50mm diameter.

6. Manufacturing Test Specimens

To evaluate mechanical properties, the sheets are manufactured according to table (3), as follows:

6.1. Tensile Test Specimens

Four specimens are formed according to standard (DIN 50125) specification, there dimensions are shown in figure (3).

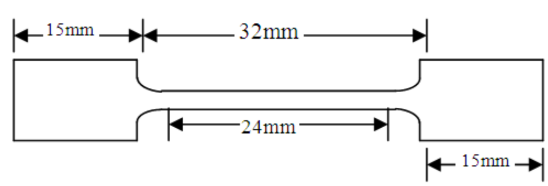

Fig.3. Tensile Specimen (DIN 50125).

7. Tests

7.1. The Rolling Process

1- Measuring grains size for specimen group before and after rolling by using optical microscope having a camera, the results are explained in table(4) and Fig.(4).

Table 4,
The Granule Size Before and After Rolling Process.

Specimen Symbol	A	B1	B2	B3	B4
Granule size (μ)	3.68	8.61	15.02	18.32	7.45

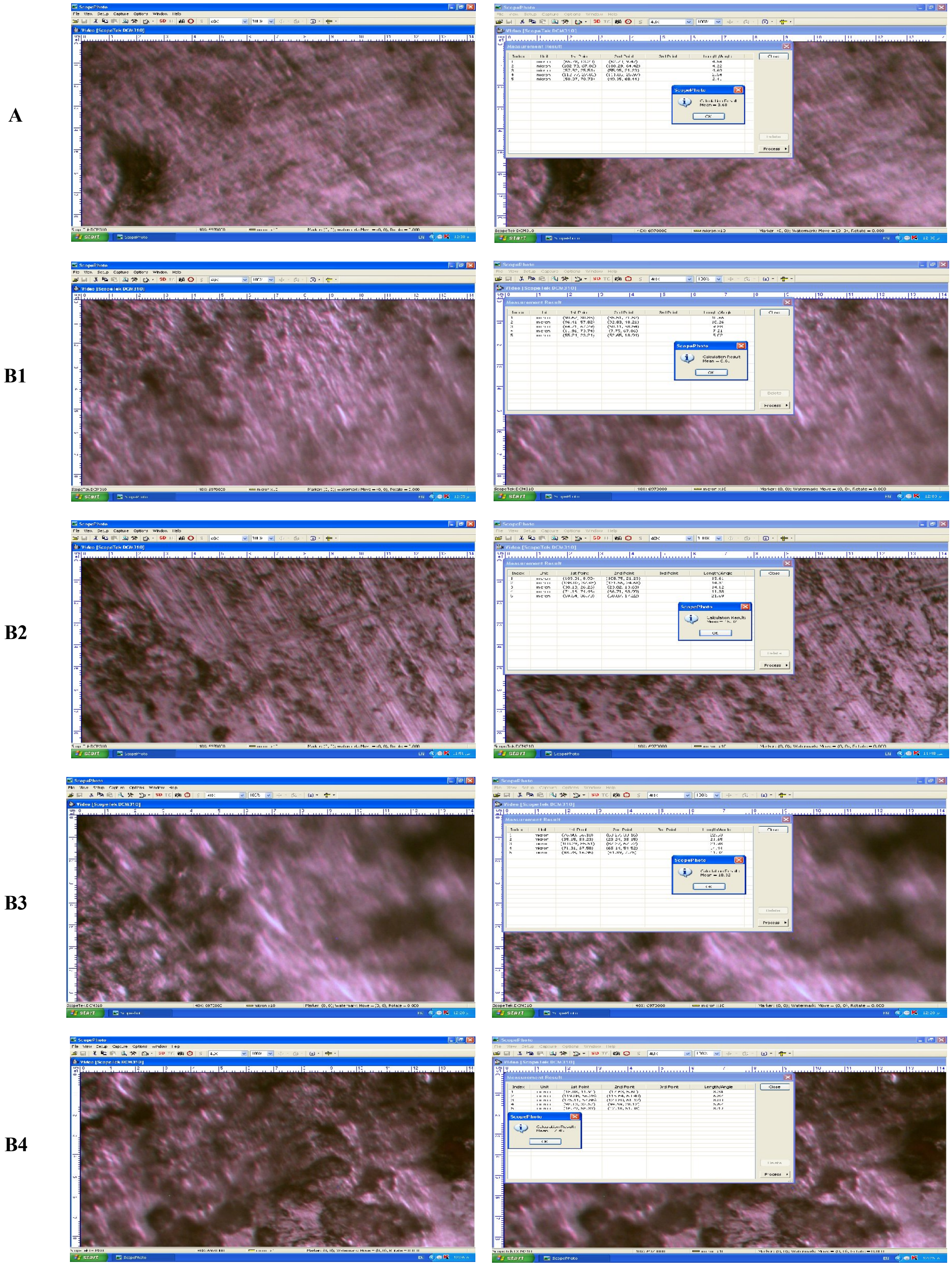

Fig.4. Microstructure for the Sheets (A), (B1), (B2), (B3) and (B4).

2- Measuring rigidity for groups of table (3) treated and untreated.

By Brinill hardness test method using a ball with 2.5mm diameter and 50kg load, the results explained in tables(5) and (6).

Table 5,
Mechanical properties of alloy after rolling without heat treatment

Specimen symbol	Thickness Mm	Number of passing	Brinill rigidity	Maximum tensile stress Mpa	Yield stress Mpa	Rolling force N
A	1.557		106	511	293.6	781
B1	1.4	4	100.5	390.5	277.6	1521
B2	1.275	6	110	426	304.3	2130
B3	1.2	10	123	474.7	339	2840
B4	1.1	12	133	512	365.8	3481

Table 6,
Mechanical properties of heat treatment alloy after rolling

Specimen symbol	Thickness Mm	Number of passing	Brinill rigidity	Maximum tensile stress Mpa	Yield stress Mpa	Rolling force N
A	1.557		91	355	253	608
C1	1.557	4	105	408	291	608
C2	1.557	4	96	373	266	608
C3	1.557	4	115	444	317	608
C4	1.557	4	103	382	306	608
C average	1.557	4	104.75	401.75	295	608

Where the heat treatment alloys C1, C2, C3 and C4 are corresponding to B1, B2, B3 and B4 respectively with constant thickness, number of passing and rolling force. It can be seen the properties is differed with each case, and it properties is much better than the untreated one.

8. ANSYS Model Generation

The ultimate purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, the model comprises all the nodes, elements, material properties, real constants, boundary conditions and the other features that used to represent the physical system.

In ANSYS terminology, the term model generation usually takes on the narrower meaning of generating the nodes and elements that represent the special volume and connectivity of the actual system. Thus, model generation in this study will mean the process of defining the geometric configuration of the model's nodes and elements. The program offers the following approaches to model generation: Creating a solid model and using direct generation. The method used in this research to generate a model is solid model. In solid modeling someone can be described the boundaries of the model, establish controls over the size and desired shape elements automatically, i.e. drawing the two dimensional specimen model and meshing using meshtool. Solid modeling is usually more powerful and versatile than other modeling, and is commonly the preferred method for generation models. The two Dimension model of specimen is done by plotting and meshing two dimension axisymmetric plane with elements, the sheet element is visco106 and the contact condition is used via elements contac171 for deformable body and target169 for rigid body.

ANSYS software is used to analyze many case in linear and non-linear (Saeed Moveni, 1999). In this study ANSYS software is used to analyze and study the forming process i.e rolling process (Kawałek, 2007) and stresses distribution in the sheet with different conditions is evaluated. The model generated for nonlinear materials and non linear geometry in addition to contact case between the sheet and roller, also it is non linear process (ANSYS, 1999). Four types of elements are used as shown in Fig. (5)

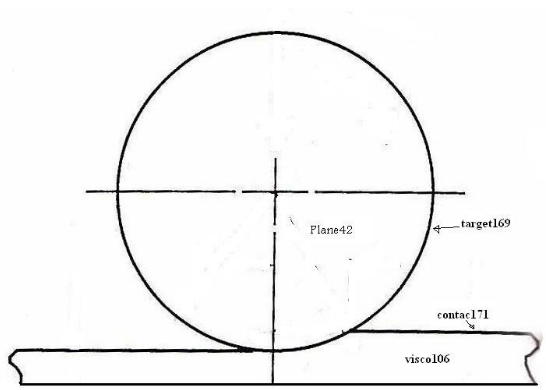

Fig.5. Rolling Process Model.

Due to symmetry, half of the rolling process is modeled. The solid modeling is used in ANSYS to make the mesh with element type visco106 for the sheet and take into consideration the contact region which is meshed with element type target169 for rigid portion and contac171 for deformed portion.

Fig.(6) shows the stress distribution in the sheet during rolling process .

9. Discussion

The aluminum-copper alloy is considered one of high strength alloys therefore it is used in many engineering applications like aircraft structure; it requires heat treatment to improve its mechanical properties. The main object of rolling is to increase length and decrease thickness with keeping width constant.

The solution heat treatment improves the mechanical properties; the rigidity increased 1.042 times, the tensile stress increased 1.028 times, the yield stress increased 1.662 times and the rolling force decreased 2.506 times.

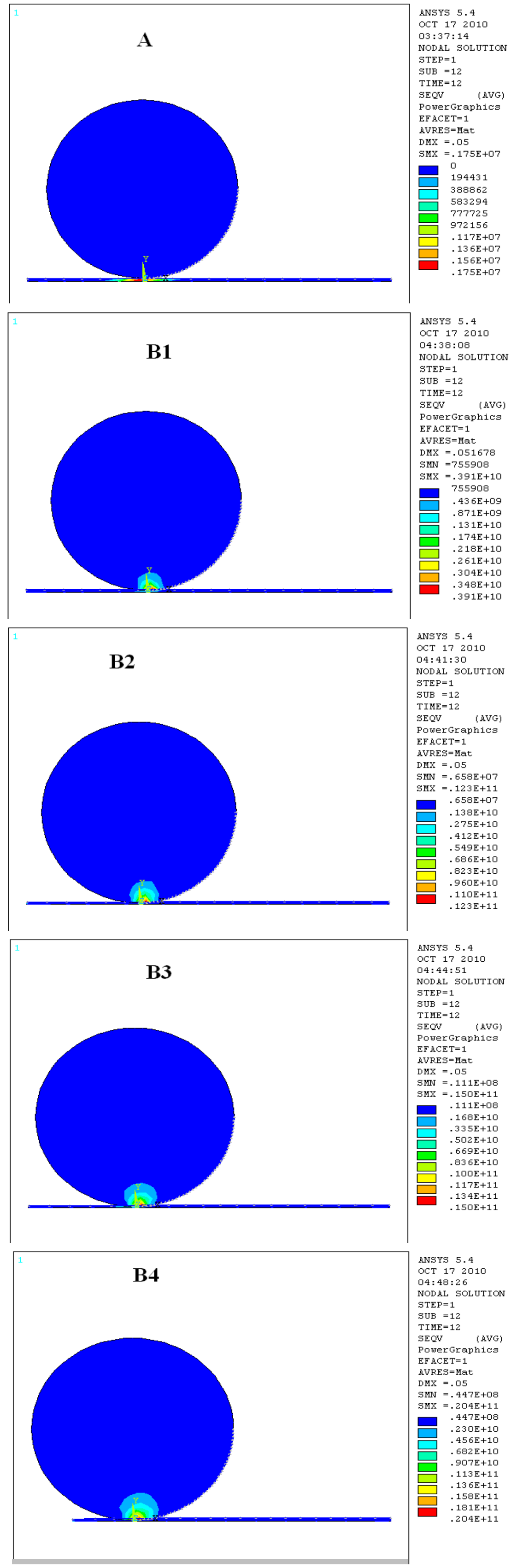

Fig.6. Stress Distribution in the Sheet during Rolling Process.

Results are taken from this research are; rigidity and tensile strength, it is found that the solution heat treatment improves the mechanical properties for (2024-T3) alloy. By decreasing number of passing between rollers, keeping thickness and a free from strain hardening. It is found that force needed for rolling untreated sheets is greater than force needed for solution heat treated because of strain hardening. The stresses' result in sheet B4 is bigger than that of sheet B3 , B2 , B1 respectively, due to the factor (h_o-h_i) is bigger in spite of the yield stress is bigger, while the stresses in sheets C1,C2,C3, and C4 is not vary significantly due to constant thickness.

10. Conclusions

It can be concluded the following:

1. Mechanical properties for the alloy without heat treatment and rolling were good because of strain hardening.
2. Mechanical properties for the alloy after heat treatment and rolling is improved 1.5% but with less force and stress compared with untreated.
3. The availability of using ANSYS program to make the rolling process and to show the stresses distribution in the alloy during rolling process.

Notation

L	the length of contact line between roller and sheet (mm).
R	radius of roller (mm).
h_o	the thickness before rolling (mm).
h_i	is thickness after rolling (mm).
Pr	roller pressure (N/mm^2).
Q_P	multiplication factor
F_r	roller force (friction) (N).
w	sheet width (mm).
T	roller torque (T.m).
V	linear velocity (m/sec).
R	roller radius (mm).

Greek letters

ρ	density (Kg/m^3).
σ	stress (N/mm^2).
σ_{tm}	flow stress (N/mm^2).
ω	angular velocity (rad/sec).

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تأثير المعاملة الحرارية المحلولية على الخواص الميكانيكية لسبيكة ألمنيوم- نحاس (2024-T3) باستعمال عملية الدرفلة

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الخلاصة

دراسة تأثير المعاملة الحرارية المحلولية على الخواص الميكانيكية لسبيكة ألمنيوم-نحاس 2024-T3 من خلال عملية الدرفلة حيث تم إجراء معاملة حرارية تضمنت تسخين صفائح من هذه السبيكة إلى درجة حرارة (480°C) ثم التبريد السريع بالماء بعدها تم إجراء عملية التشكيل اللدن (الدرفلة) على هذه الصفائح المقساة ثم إجراء عملية تعتيق طبيعي لمدة شهر بعدها تم الحصول على الخواص الميكانيكية من مقاومة شد وصلادة حيث تم إجراء عملية التشكيل بواسطة عملية الدرفلة من خلال تمرير الصفائح بين درافيل وبنسب تشكيل متعددة ومقارنة النتائج للمعدن بدون تعامل. تم استخدام برنامج ANSYS لدراسة توزيع الاجهادات في عملية الدرفلة. وقد تبين ان الخواص الميكانيكية للسبيكة بدون تعامل حراري افضل بسبب ما يسمى بالاصلاد الانفعالي والخواص الميكانيكية للسبيكة بعد المعاملة الحرارية والدرفلة تحسنت ايضاً ولكن بجهد وقوى اقل مقارنة بتلك التي اجريت بدون معاملة.
