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Machining and Tensile Properties of Warm Squeezed 7075 Aluminum Alloy

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Abstract

This study is aims to improve the properties of aluminum alloy 7075 by conducting heat treatment and mechanical processing. The development experiment was carried out by subjecting the samples to the process of warm squeezing, as well as conventional heat treatment. An improvement in the tensile and machining properties of the samples was noticed after the warm squeezing process. The warm squeezing caused the elongation percentage, yield strength, and the tensile strength of the heat-treated sample to increase by 11%, 40%, and 19% respectively. In addition, a significant increase of 62%, 94% and 191% in the plastic behavior of the squeezed sample was observed during the tensile test at temperatures 200, 250 and 300°C respectively. The mechanical warm squeezing showed an improvement in the machining characteristics of the alloy, as it reduced the surface roughness by 66%, but it increased the cutting force by 34%.

Keywords: Warm Squeezing, Superplasticity, Machinability, 7075 Al Alloy

1. Introduction

Super plastic 7075 aluminum alloy is a popular choice for research and development in various industries due to its unique combination of properties like high specific strength, acceptable machinability, and being heat treatable. Therefore, it has wide range of applications. Its properties particularly advantageous in aerospace, automotive, defense industries and in industries where weight reduction is a primary concern, such as transportation [1, 2]. Using lighter materials like 7075 aluminum can enhance fuel efficiency, improve performance, and reduce overall costs. The performance of Al-Zn-Mg alloys has

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been examined in numerous published papers. **Haydar Al-Ethari et al. in [3]** studied the effect of mechanical and thermo mechanical treatment on the microstructure and the hardness of Al5Zn1.8Mg alloy prepared by stir casting. **Moazam M. et al. in [4]** studied the Distribution of the residual stresses due to precipitation hardening, stress relieving by cold compression and stress relieving by heat treatment of AA 7075. **Balasubramanian et al. in [5]** studied superplastic parameters such as the yield and the ultimate stresses, temperature, strain rate and strain rate sensitivity index by using hot tensile test method in AA 7075 alloy in experimental and numerical simulation method. **Lin et al. in [6]** studied the microstructure evolution of annealed 7075 aluminum alloy and its influence on room-temperature plasticity. **Ping Zhang et al. in [7]** investigated the effect of heat treatment process on the micro machinability of the 7075 aluminum alloy.

The current work focused on studying the warm squeezing influence on the tensile properties and the machinability of the 7075 Al-alloy.

2. Experimental Procedure

2.1. Materials Used in the Present Study

To achieve the goal of the current study, zinc, mg, copper powders of 99.9% purity were used as well as aluminum wires with the chemical composition of which is shown in Table(1). The analysis was carried out at the General Company for Engineering Testing and Qualification/ Baghdad.

Table (1): Chemical Composition of the Used Aluminum Wire

material	Chemical Composition or Source								
Element	Al	Fe	Mg	Si	Zn	Ti	Cr	Cu	Other Elements
Wt.%	99.7	0.113	0.1201	0.022	0.02	0.004	0.003	0.001	0.0169

2.2. Preparation of the Alloy Samples:

The 7075 alloy samples were prepared by stir casting method, homogenized at 520°C for four hours, then heated to 470°C at a rate of 10 degrees per minute. This temperature was maintained for 6 hours before the samples were rapidly cooled in ice water. Subsequently, the samples were heated to 120°C for five hours and slowly cooled inside the furnace. Table (2) displays the composition of the prepared samples.

Table (2): Composition of the Prepared 7075 Al Alloy Samples

Element	Zn(%)	Mg(%)	Cu(%)	Mn(%)	Fe(%)	Si(%)	Al(%)
Prepared Samples	5.4	2.3	1.3	0.006	0.4	0.08	Bal
Standard (%)[8]	5.1-6.1	2.1-2.9	1.2-2	Max. 0.3	Max. 0.5	Max. 0.4	Bal

The samples were subjected to a warm squeezing using a pressure of 140MPa at 120°C for 10 minutes [9]. The squeezing pressure was employed to cylindrical specimen having 15mm- diameter and 165mm length. The specimen was fitted in a steel die having a cavity of the same dimensions as those of the specimen [9].

According to specifications in ASTM, vickers hardness test (E10-15a), porosity test (B 328 - 96), density tests (D-792), grain size measurements were carried out and the results are shown in Table (3) [9].

Table (3): Hardness, Porosity, Density, and the Grain Size of the Alloy Sample [9]

Property	Specimen before heat treatment	Specimen after heat treatment	Specimen after heat treatment and squeezing by 140 MPa
Hardness Hv	97	156	209
Porosity (%)	20	20	4
Density (g/cm^3)	2.76	2.76	2.89
Grain size (nm)	962	962	655

3. Tests, Results and Discussions

3.1. X-ray Diffraction (XRD) Analyses.

The experimental setup involved the following conditions: Copper (Cu) was used as the target material, with a wavelength of 1.54060A °. The current and voltage applied were 15mA and 30kV, respectively. The scanning speed was set at 2° per minute, covering a range

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from 20° to 90° . X-ray diffraction was employed to identify the phases present in the heat-treated Al-Zn-Mg alloy and subsequently compare them with standard diagrams (JCPDS, C and No.09-0432). Figure (1) displays the XRD analysis outcomes of the processed and heat-treated 7075 Al alloy, along with the positions of the resulting diffraction peaks. These phases are formed through a process of heating the alloy to a high temperature and rapidly cooling it, followed by subsequent heating and slow cooling. These particular phases are known for their remarkable strength and hardness, and they significantly influence the alloy's properties, particularly in terms of the strength, the elasticity, the wear resistance, and the hardness.

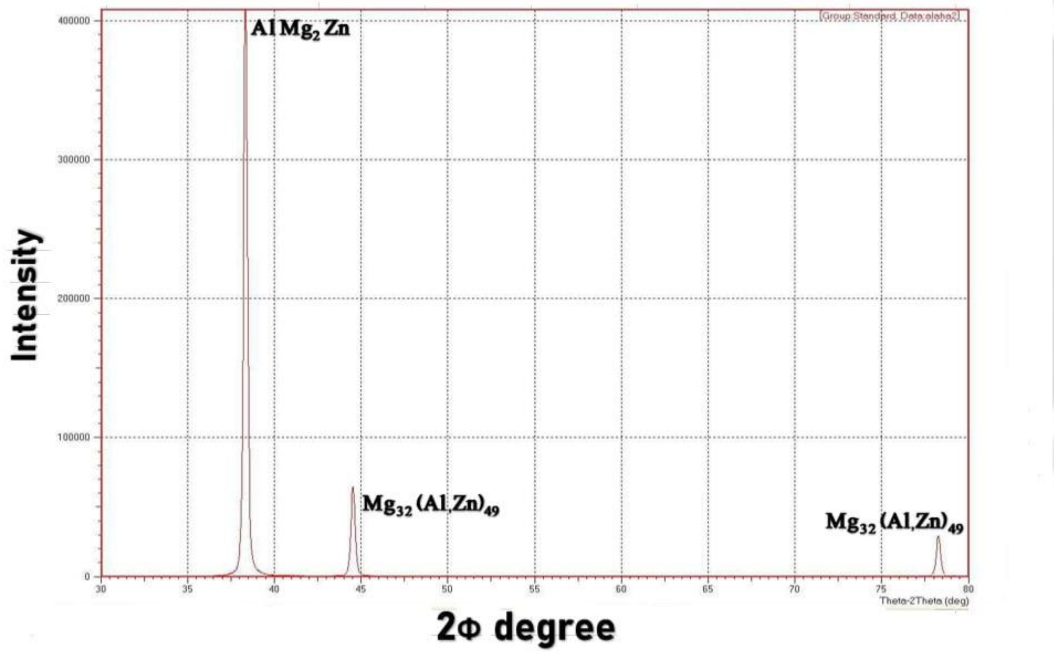

Figure (1): XRD Analysis on the Heat Treated 7075 Al Alloy

3.2. Tensile Test

According the ASTM (B557m-15) guidelines [10], standard samples were prepared using the dimensions illustrated in Figure (2).

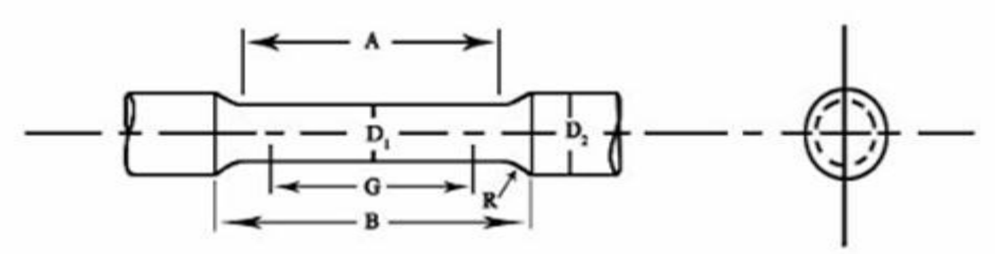

Figure (2): Standard Round Tensile Test Specimen [11]

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Where: Radius of fillet (R): 6 mm; Gage length (G): 35 mm; Diameter (D): 8.75 mm; Length of reduced section (A): 45 mm

The samples underwent polishing to eliminate any surface flaws. The experiments were conducted using a computer-controlled universal testing machine (model WDW) at a speed rate of 0.2 mm/min. The tests were performed at different temperatures. To facilitate the tests, a specially designed heating system incorporating a heating element and a thermocouple shown in Figure. (3), was employed to measure and control the temperature.

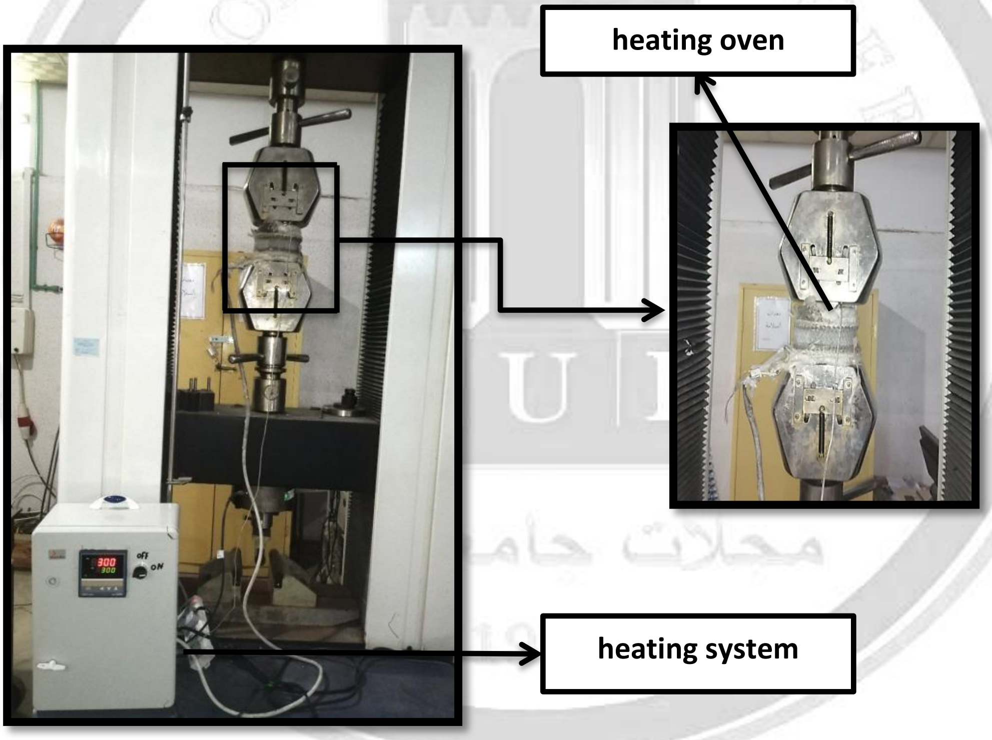

Figure (3): Tensile Testing Machine with Heating System

By conducting the tests at different temperatures, the objective was to ascertain the impact of temperature on the ultimate tensile strength, the yield strength and the elongation percentage of the alloy. The results are recorded in Table (4).

These values offer valuable insights into the mechanical behavior and strength of the 7075 Al alloy that have undergone heat treatment and warm squeezing. It is important to note that the standard alloy exhibits a tensile strength of 575MPa [12]. The samples before and after undergoing the testing are depicted in Figure (4)

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Table (4): Results of the Tensile Tests

sample	Testing Temperature °C	Ultimate Tensile Strength (MPa)	Elongation (%)	Yield Point (MPa)
Heat treated only	20	565	11	507
Heat treated only	300	310	162	211
Heat treated and squeezed by 140MPa	20	674	40	583
Heat treated and squeezed by 140MPa	200	473	62	387
Heat treated and squeezed by 140MPa	250	390	94	300
Heat treated and squeezed by 140MPa	300	345	191	237

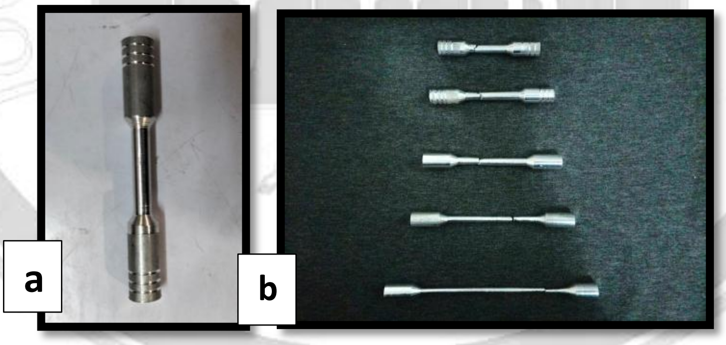

Figure (4): Tensile Specimen (a): Before Testing (b): After Testing Where: Radius of Fillet (R): 6 mm; Gage length (G): 35 + 0.5 mm; Diameter (D): 8.75 + 0.25 mm; Length of Reduced Section (A): 45 mm.

The test results at the ambient temperature clearly demonstrate that the tensile strength increases and the elongation slightly increases for the sample subjected to warm squeezing. Conversely, as the temperatures gradually rise, the elongation significantly increases while the tensile strength decreases. This information is illustrated in Figure (5), which depicts the stress-strain curve for laboratory samples.

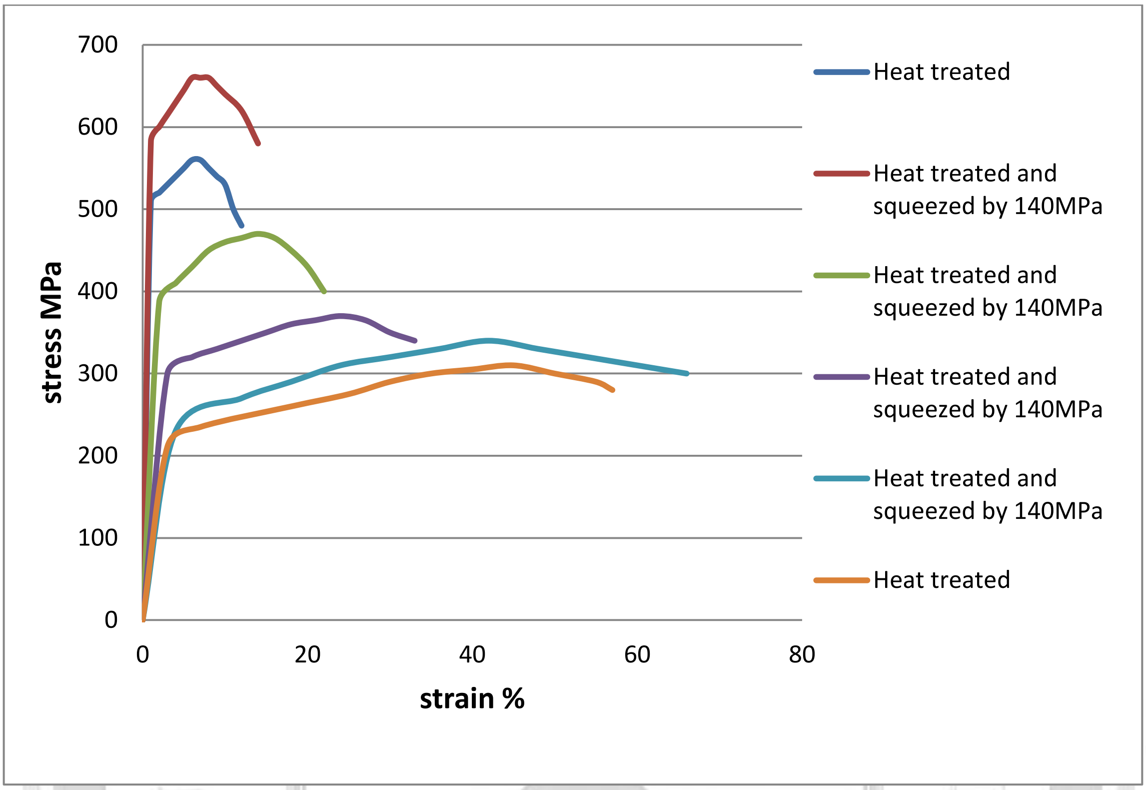

Figure (5): The Stress-strain Curve for Laboratory Samples

3.3. Fracture shape analysis.

The examination of the fracture's form provides valuable insights into the material's properties such as tensile strength, elasticity, and energy absorption capacity prior to failure. By employing electron microscopy to scrutinize the fracture surface due to the tensile test, distinct features and indications can be identified, shedding light on the fracture type and material behavior. In the laboratory samples, visual evidence confirms the presence of granule displacement across the surface due to accumulated plastic deformations resulting from the applied tensile force, as illustrated in Figure (6).

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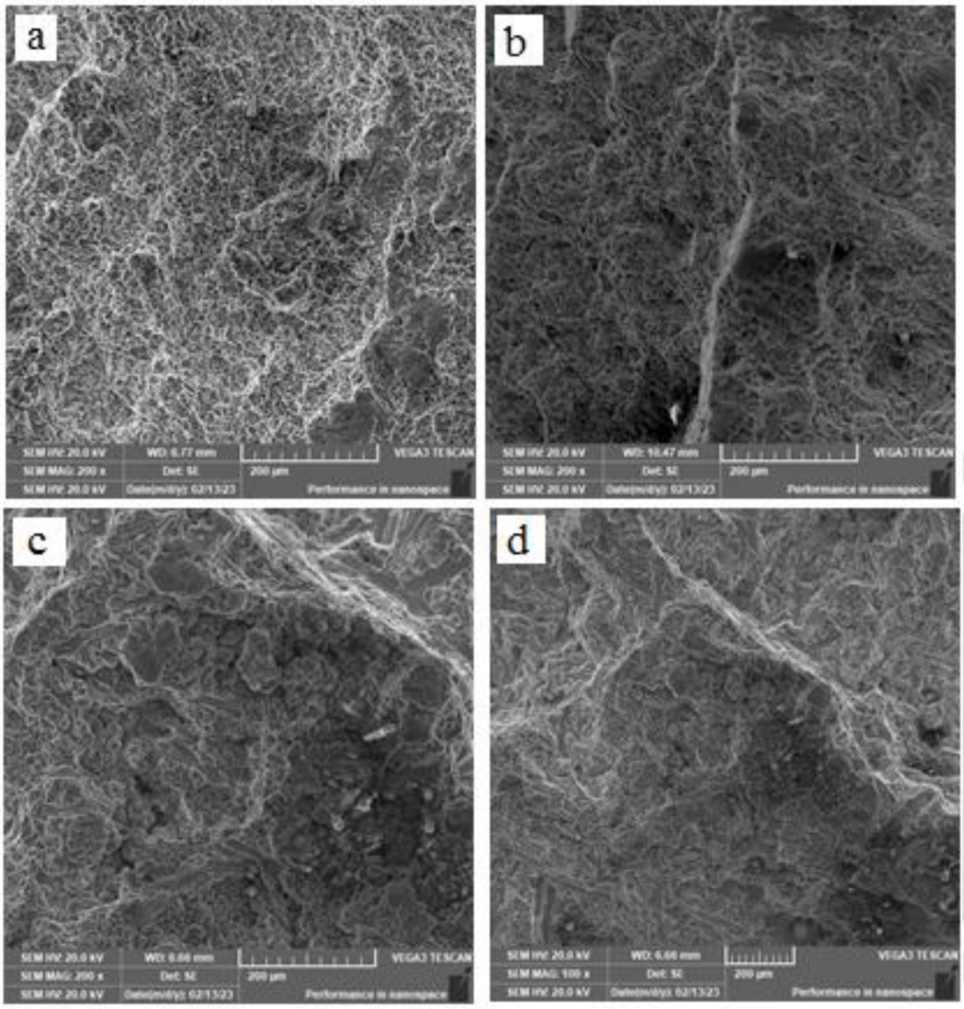

Figure (6): SEM Images of the Fracture Shape : (a) Heat Treated and Tested at 20°C; (b) Heat Treated, Squeezed by 140MPa and Tested at 20°C; (c) Heat Treated and Tested at 300°C; (d) Heat Treated, Squeezed by 140MPa and Tested at 300°C

The fracture takes the form of a tilted shear fracture at an angle, caused by extensive deformation. The angle of the fracture corresponds to the inclination of the fracture plane in relation to the plane perpendicular to the direction of tension. For the samples tested at the ambient and at the elevated temperaturs, the angle is minimal for heat-treated and squeezed samples due to their strength and uniformity, while it is greater for heat-treated samples that have not undergone squeezing due to internal flaws.

3.4. Machinability Test of the Alloy Samples.

The machining tests were carried out on a turning machine type ZMM-Sliven/Bulgaria model. The machine is equipped with a 2.2 kW motor, and having a spindle speeds ranged

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from 20 to 2000 rpm, with a feed varied from 0.015 to 0.6 mm/rev. P10-type cemented carbide tips were utilized. These tips consisted of 65% tungsten (WC), 9% cobalt (Co), and a combination of 26% tantalum carbide (TaC) and titanium carbide (TiC). They were designed with four cutting edges, a tool angle of 55°, and a nose radius of 1.6 mm. To hold the tool, an AG.CO tool holder type was used. Dry turning was carried out with a constant cutting depth of 0.2 mm. Three different cutting speeds were employed: 7 m/min, 14 m/min, and 52 m/min. and, two feed were applied: 0.130 mm/rev and 0.70 mm/rev.

The machinability of the alloys was investigated by assessing the cutting force, the roughness of the machined surface, and the shape and size of the resulting chip. A cutting force dynamometer was utilized to measure the forces applied to the cutting tool during machining. Figure (7) illustrates the dynamometer and its arrangement on the lathe.

Figure (7): The Dynamometer and its Amengment on the Lath

To evaluate the roughness of the machined surface, a roughness tester type (HSR 210 Roughness Tester-China) was employed. All measurements were taken after the first minute of cutting. The maximum reading was directly recorded, and the average of three readings was documented for each machining process. Additionally, an image of the chip shape produced by each machining process was captured to gain insights into the deformation behavior of the alloy during processing. The analysis of cutting forces involved two models: one that underwent heat treatment alone and another that underwent both heat treatment and exposure to warm squeeze as shown in table (5).

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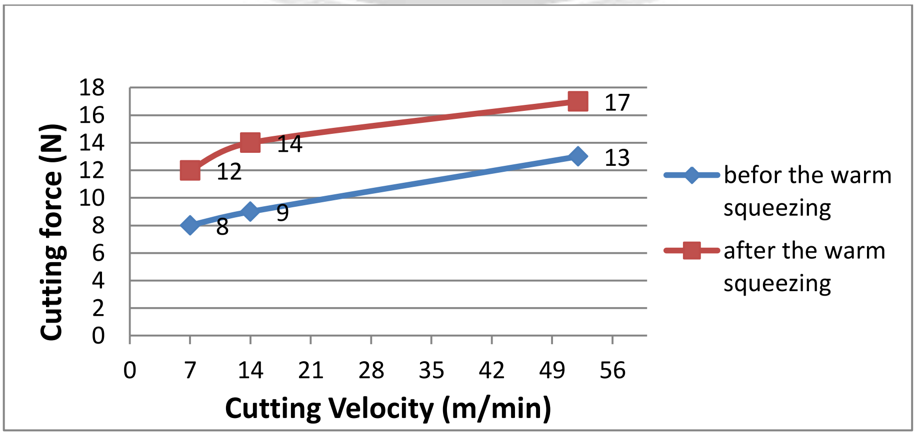
Table (5): Codes of the Alloy Samples with the Machining Condition

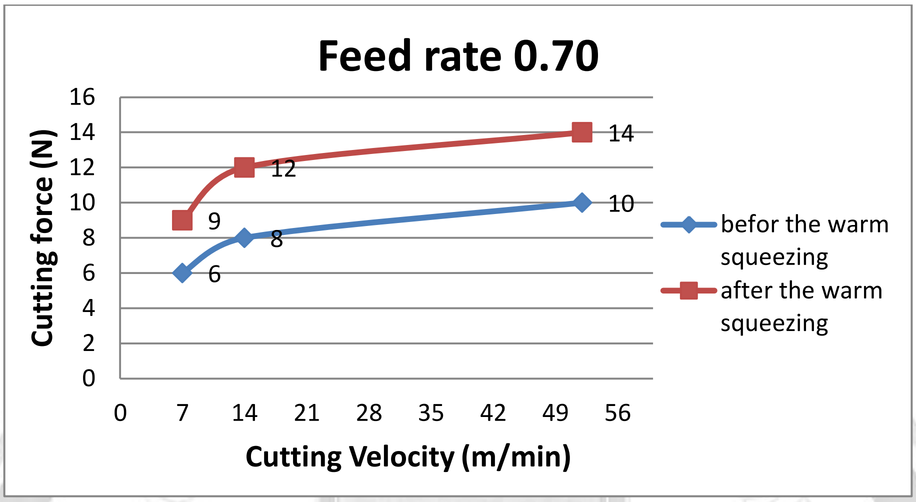
Sample	Sample code	Vc(m/min)	Feed(mm/rev)
Before squeezing	S0	7	0.130
	S1	14	
	S2	52	
	S3	7	0.70
	S4	14	
	S5	52	
After squeezing by 140MPa	S6	7	0.130
	S7	14	
	S8	52	
	S9	7	0.70
	S10	14	
	S11	52	

3.5.1. Cutting Force Test

The results revealed that the warm squeezing process. This process effectively reduced internal flaws, improve the crystal structure, enhance its overall organization by reducing voids and pores. Consequently, the strengthened crystal structure led to an increase in the required cutting force. Figures (8) and (9) visually represent the variation in the cutting forces before and after the warm squeezing procedure.



Figures (8): Change of Cutting Force Before and After Warm Squeezing at a Feed of 0.130 mm/rev



Figures (9): Change of Cutting Force Before and Before Warm Squeezing at a Feed of 0.70 mm/rev

3.5.2. Test of the Surface Roughness.

The decrease in friction during the machining process reduces the heat-induced deformations that could negatively affect the surface quality. Figures (10) and (11) illustrate the contrast in roughness between two samples tested before and after warm squeezing. The squeezed sample exhibits improved surface roughness due to reduced porosity and gaps in the alloy. It should be noted that increasing the feeding is associated with an increase in surface roughness. This can be attributed to factors such as higher cutting force applied to the tool. Moreover, a higher feeding rate can cause more vibrations during operation and put greater pressure on the workpiece, resulting in elevated temperature. These factors can contribute to the formation of metal films or changes in the mechanical properties of the material, ultimately leading to an escalation in surface roughness.

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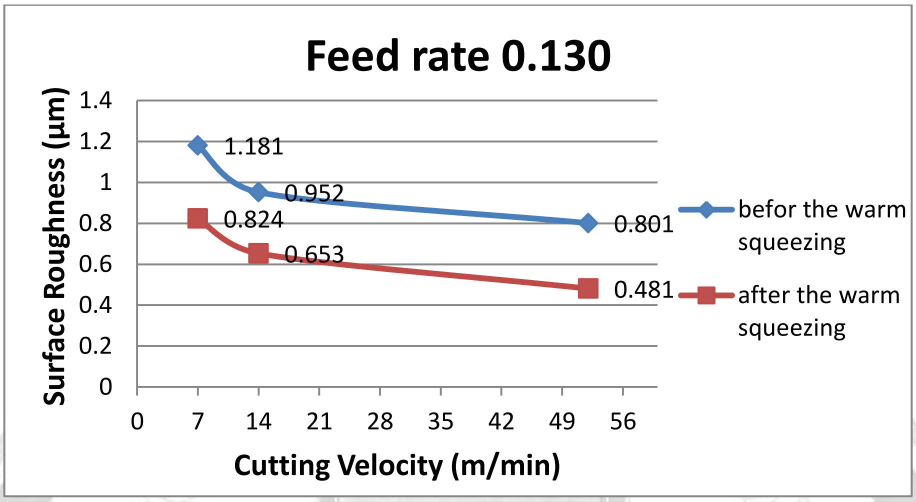
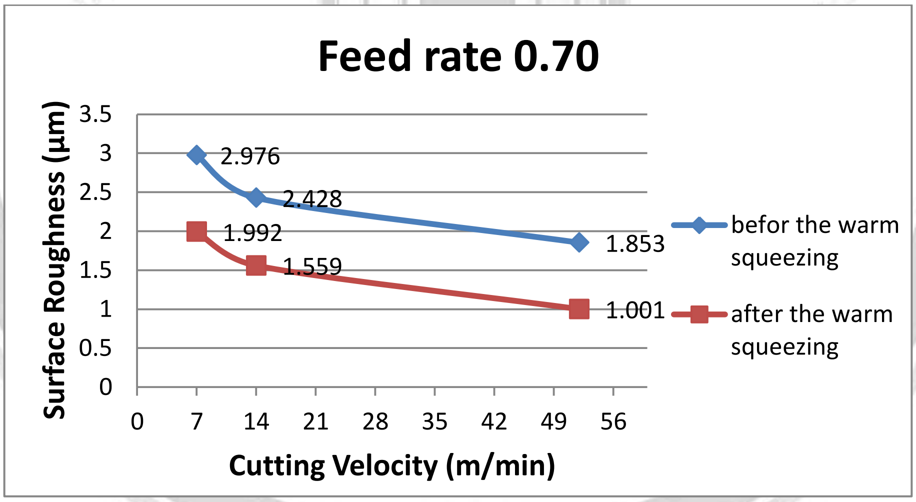


Figures (10): Effect of Cutting Speed on Sample Surface Roughness Before and After the Hot Press Used at a Cutting Depth d = 0.2 mm and a Feed of (0.130 mm/rev)



Figures (11): Effect of Cutting Speed on Sample Surface Roughness Before and After the Hot Press Used at a Cutting Depth d = 0.2 mm and a Feed of (0.70 mm/rev)

3.5.3. Chip Shape Analysis.

Figure (12) illustrates the chip shapes produced according to the machining conditions mentioned in table (5). Understanding the machinability of an alloy and determining the best cutting parameters for efficient operations relies heavily on the analysis of chip formation and its impact on the machining process. The characteristics of the chips produced during machining offer valuable insights into the alloy's machinability. Factors such as chip shape, size, and color provide information about the cutting process and the interaction between the tool and the workpiece. Ideally, long and continuous chips indicate favorable machinability, whereas fragmented or discontinuous chips suggest potential challenges.

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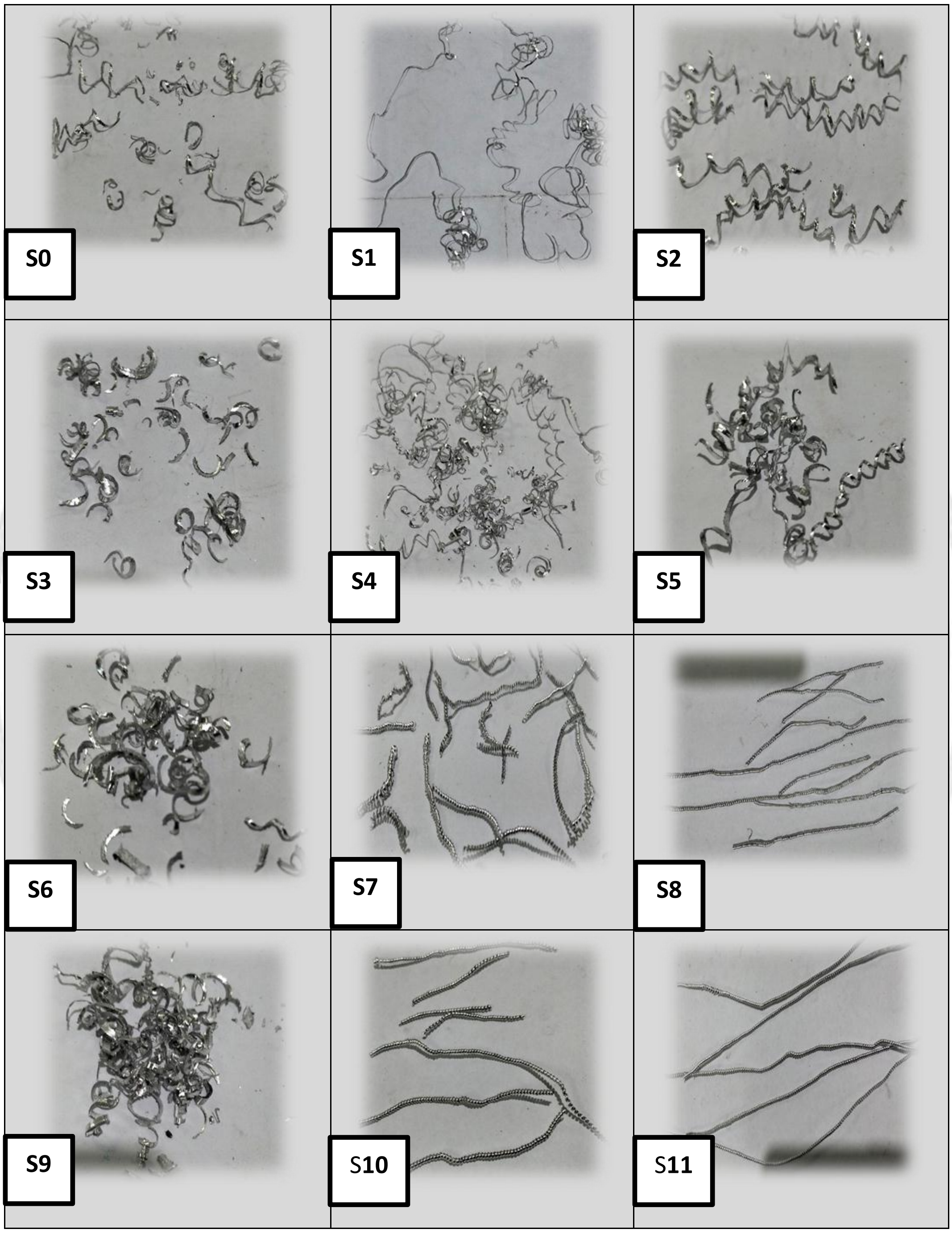

Figure (12): The Shapes of the Chip Formed

As the cutting velocity increases, the chips appearance changes, losing their fine quality and suggesting that higher cutting speeds produce thicker chips. When the feeding rate goes up, the chips can become distorted and discretions. Particularly, higher feed rates can result in chips getting tangled or cracked. Furthermore, applying warm squeezing helps create a more

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continous chips by reducing the grain size, and the porosity, which means increasing the toughness of the alloy sample.

4. Conclusions

The findings can be summarized as follows:

1- The warm squeezing increases the tensile properties of the 7075 Al alloy. At the ambient temperature the elongation percentage, yield point, and the tensile strength recorded improvement by 264%, 15%, and 20% respectively, whereas at 300 ^{0}c these improvements were 18%, 13%, and 12%.

2-Warm squeezing improved the machining properties of the 7075 Al alloy. It led to 66% reduction in surface roughness, but 34% increase in the cutting force due to the range of the employed machining conditions was recorded.

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خواص التشغيل والشد لسبائك الألومنيوم ٧٠٧٥ المعصورة على الدافئ

محمد المهدي هاتف المحنه، حيدر العذاري، طالب عبد الامير الجاسم

قسم هندسة المعادن/ كلية هندسة المواد/ جامعة بابل

الخلاصة

تهدف هذه الدراسة إلى تحسين خواص سبائك الألومنيوم ٧٠٧٥ عن طريق إجراء المعالجة الحرارية والمعالجة الميكانيكية. وتم تنفيذ تجربة التطوير من خلال إخضاع العينات لعملية العصر الدافئ، بالإضافة إلى المعالجة الحرارية التقليدية. وقد لوحظ تحسن في خصائص الشد والتشغيل للعينات بعد عملية العصر الدافئ. أدى العصر الدافئ إلى زيادة نسبة الاستطالة، ومقاومة الخضوع، ومقاومة الشد للعينة المعالجة حرارياً بنسبة ١١%، ٤٠%، و١٩% على التوالي. بالإضافة إلى ذلك، لوحظ زيادة ملحوظه قدرها ٦٢%، ٩٤% و ١٩١% في السلوك اللدن للعينة المعصورة أثناء اختبار الشد عند درجات حرارة ٢٠٠، ٢٥٠ و ٣٠٠ درجة مئوية على التوالي. أظهر العصر الميكانيكي الدافئ تحسنًا في خصائص تشغيل السبيكة، حيث قلل من خشونة السطح بنسبة ٦٦%، لكنه زاد من قوة القطع بنسبة ٣٤%.

الكلمات الدالة: العصر الدافئ، اللدونة الفائقة، قابلية التشغيل، سبيكة آل ٧٠٧٥