

**MICROSTRUCTURE AND MECHANICAL PROPERTIES FOR ALUMINUM 2024
CHIPS OF VARIOUS PREHEATING TEMPERATURES AND TIMES
MANUFACTURING BY HOT EXTRUSION PROCESS**

**Ahmed Sahib Mahdi^{1,a}, Mostafa Abbas Jabbar^{1,b}, Saad Jabbar Nghaimesh^{1,c}, Mohd
Sukri Mustapa^{2,d}, Mohd Amri lajis^{2,e}**

¹ *Al-Nasiriya Technical Institute, Southern Technical University (STU), Iraq*

² *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn
Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

E-Mail: ^a ahmed.altaei@stu.edu.iq , ^b m.jabbar@stu.edu.iq , ^c saad.nghiamesh@stu.edu.iq, ^d
sukri@uthm.edu.my,
^e amri@uthm.edu.my

Abstract:

The preheating temperature and time for hot extrusion are determined by various factors, such as the composition of the material being extruded, the desired characteristics of the end product, and the specific parameters of the extrusion process. Preheating is typically required to enhance the material's pliability and facilitate the extrusion procedure. The preheating temperature exhibited significant variation, ranging from 400 to 500 degrees and the time ranging from 0.5 to 2.5 hr. in the present study. Three groups were chosen according to variety of preheating temperature and time. As a results, the best temperature was obtained by the specimen B (preheating temperature 450, preheating time 0.5 hr.). the result of density was 2.78 g/Cm³, While the hardness value was 150 Hv, so the ultimate tensile strength was 470 MPa. The process efficiency in current research was 76%, it was concluded by homogeneous and non-homogeneous strain.

Key words\ preheating temperatures, Hot extrusion, homogeneous strain, mechanical properties, aluminum 2024.

1. Introduction:

Hot extrusion is a manufacturing technique employed to produce elongated and uninterrupted structures and components from a range of materials, such as metals, polymers, and ceramics [1,2]. This procedure entails subjecting the material to elevated temperatures, usually surpassing the recrystallization threshold in the case of metals, rendering it more pliable and facilitating deformation [3,4]. The main objective of hot extrusion is to manipulate and mold the material into a certain cross-sectional configuration, such as a rod, tube, or intricate shape [5,6]. The initial material is processed, typically in the shape of a billet (a cylindrical or rectangular piece of the material) or a preform [7,8,9]. For metallic materials, the usual practice is to heat them to a temperature higher than their recrystallization point, which varies based on the particular metal. A die, functioning as a tool or mold, is specifically engineered to produce the intended cross-sectional configuration of the extruded item [7]. The die possesses an aperture that corresponds to the desired form of the outcome. The thermally elevated substance is inserted into a receptacle, commonly known as a container or billet

holder [10,11,12]. A ram or plunger is employed to exert force on the material, propelling it through the die. The material experiences deformation as it passes through the die, adopting the form of the die's aperture. The extruded product is produced continuously and can be precisely trimmed to the necessary length [10]. The extruded product may be cooled to harden its shape and properties. Further refining using cutting, machining, or surface treatments may be needed to achieve the desired product quality. The process of hot extrusion is extensively employed across several sectors to manufacture components such as pipes, rods, profiles, and structural forms, particularly for the production of metals and alloys. Benefits of this approach encompass enhanced material characteristics, diminished porosity, and the ability to fabricate intricate forms with exact measurements [11]. Nevertheless, the utilization of this technology is contingent upon a regulated setting and elevated temperatures, hence potentially restricting its suitability to particular substances and specific circumstances [13,14].

Hot extrusion is a manufacturing technique that involves pushing a heated material through a die aperture to produce items with a predetermined cross-sectional shape. This procedure is frequently employed with metallic substances; however, it can also be utilized with other materials like as polymers, ceramics, and composite materials. Here is a brief overview of the hot extrusion process [15,16,17]:

- 1- **Material Preparation:** The initial stage involves the preparation of the material, typically in the shape of a billet or a cylindrical bar. The material is exposed to high temperatures, typically above its recrystallization point but staying below its melting point. The exact temperature depends on the particular substance being extruded. **Billet Loading:** The billet, which is a hot material, is inserted into a container or chamber of an extrusion press.
- 2- An extrusion press comprises a hydraulic ram and a die. A die is a specialized tool with a distinct form or profile that is located at one end of the extrusion chamber. The ram is powered by hydraulic force and propels the billet forcefully through the die.
- 3- Extrusion is the application of hydraulic pressure to propel a heated billet through the opening of a die. The material conforms to the shape of the die and is extruded from the die's outlet in the intended configuration.
- 4- **Cooling and Cutting:** After the material has been extruded through the die and has obtained the correct shape, it can undergo a cooling procedure to prevent any deformation or warping during the cooling phase. Subsequently, it is trimmed to the desired length.

The process of hot extrusion is commonly employed in the manufacturing of a wide range of goods, such as pipes, tubes, rods, bars, and structural shapes. The extrusion method enables the formation of intricate structures with enhanced mechanical characteristics by inducing material recrystallization. Recrystallization facilitates grain size reduction and improves the material's characteristics. Compared to cold extrusion, hot extrusion requires higher temperatures and is more suitable for materials that are difficult to deform at room temperature, like many metals. The process also provides greater control over the product's dimensions and allows for tighter tolerances.

Homogeneous strain equations are used to describe the deformation of a material or structure under the influence of external forces or loads [2].

$$\epsilon_H = \sqrt{\frac{2}{3}(\epsilon_x - \epsilon_y)^2 + (\epsilon_y - \epsilon_z)^2 + (\epsilon_z - \epsilon_x)^2} \quad \text{----- 1}$$

$$\epsilon_x + \epsilon_y + \epsilon_z = 0 \quad \text{-----2}$$

The final equation for homogeneous strain is as follows:

$$\epsilon_H = \sqrt{\frac{2}{3}(\epsilon_x^2 + \epsilon_y^2 + \epsilon_z^2)} \quad \text{----- 3}$$

The following equations pertain to nonhomogeneous strain.

$$d\epsilon_l = \frac{dA}{A} \quad \text{----- 4}$$

$$\epsilon_l = 2 \ln \frac{r_o}{r_i} \quad \text{-----5}$$

$$\epsilon_r = \epsilon_c = \ln \frac{r_o}{r_i} \quad \text{----- 6}$$

$$\epsilon_T = \sqrt{\frac{2}{3} \left[\frac{3}{2} \epsilon_H^2 + \frac{1}{2} (\epsilon_l^2 + \epsilon_r^2 + \epsilon_c^2) \right]} \quad \text{-----7}$$

Redundancy strain factor refers to the measure of stress or pressure caused by the presence of unnecessary or repetitive elements. The value of ϕ can be obtained by dividing the total strain by the homogeneous strain, as shown below.

$$\phi = \frac{\epsilon_T}{\epsilon_H} \quad \text{----- 8}$$

The efficiency of the extrusion process, denoted by η , can be determined using the following calculation:

$$\eta = \frac{1}{\phi} \quad \text{-----9}$$

2. EMPIRICAL INVESTIGATION

2.1. Material used

The selection of material for hot extrusion is contingent upon the particular application and the desired qualities of the final product. Aluminum and its alloys are frequently subjected to extrusion processes to manufacture a diverse array of items, such as profiles utilized in construction, automotive components, and various other applications. The current research employed Aluminum 2024. Table 1 exhibits the chemical composition of the metal utilized in the article.

Table 1 chemical composition

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Values	90.7-94.7	0.1	4.5	0.5	1.5	0.6	0.5	0.15	0.25

Mechanical qualities refer to the inherent traits of materials that determine their response to different types of external forces or loads. These properties offer useful insights into the behavior of a material under various conditions and are crucial for the design and engineering of applications. Table 2 shows mechanical properties.

Table 2 shows mechanical properties.

Property	Value
----------	-------

Density	2.78 g/ cm ²
Hardness	137 V
Maximum tensile strength	440 MPa
Yield strength	290 Mpa
Elongation	10%
Elasticity modulus	73.1 Gpa
Poisson's ratio	0.33
Fatigue strength	138 Mpa
Shear modulus	28Gpa
Shear strength	283 Mpa
Annealing temperature	413°C
Melting point	502 – 638 °C

2.2. Sample Preparation

Sample preparation encompasses the systematic gathering, manipulation, and conditioning of specimens or samples to ensure their suitability for laboratory examination or testing. The efficacy and precision of the outcomes derived from several analytical methodologies hinge upon the meticulous preparation of the samples. Figure 1 illustrates the extrusion die and specimen before the extrusion process.

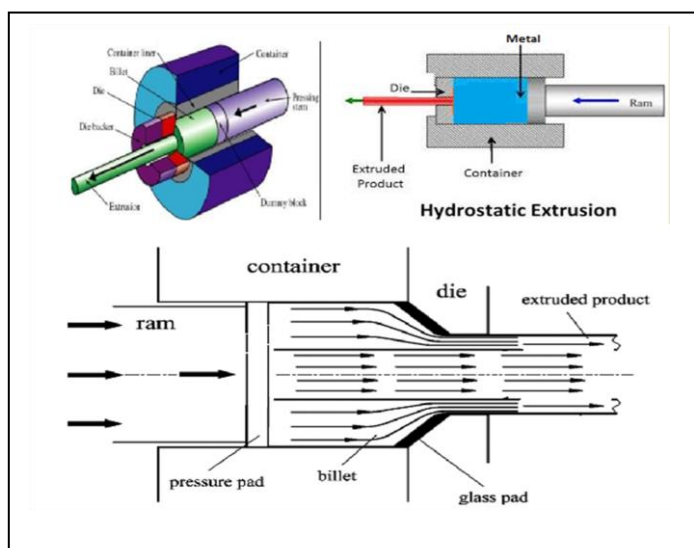


Figure 1 Extrusion die and specimen

Table 3 classification of the specimens

Symbols	Sub symbols	Preheating temperature ($^{\circ}\text{C}$)	Preheating times (hrs.)
A	A1	400	0.5
	A2	400	1.5
	A3	400	2.5
B	B1	450	0.5
	B2	450	1.5
	B3	450	2.5
C	C1	500	0.5
	C2	500	1.5
	C3	500	2.5

2.3 specimen classification

Specimen classification involves the systematic grouping of specimens or samples according to their distinct traits, attributes, or criteria. The categorization is crucial for the systematic arrangement, recognition, and administration of specimens in a laboratory or research environment. Nine specimens were chosen to perform the current paper. The classification criteria employed can exhibit significant variation, contingent upon the specific topic of research and the characteristics of the specimens being examined. Table 3 presents the classification of the specimens.

2.4 Parameters setting of the hot extrusion process

Parameter setting involves the act of configuring and fine-tuning different parameters or settings within a system, device, or any other technological or mechanical system. The objective of parameter setting is to enhance the performance, functionality, and behavior of the system according to specified needs or objectives. The adjustable settings differ based on the system. Table 4 shows the parameters setting.

Table 4 Hot extrusion parameters configuration

parameter	Value
Extrusion die form	Round
Extrusion ratio	4
Diameter of billet	30 mm
Rate of extrusion	1 mm/s
Container heat.	300 $^{\circ}\text{C}$
Die temp.	300 $^{\circ}\text{C}$

3.0 RESULT AND DISCUSSION

This part functions as a forum for showcasing the findings of the research or experiments and engaging in a thorough conversation about the consequences and importance of those conclusions.

3.1 Process efficiency of extrusion

Depending on the context and purposes of the extrusion process, its efficiency can be assessed in several ways. Efficiency can be quantified in terms of output per unit of input (e.g., product produced per unit of energy or material) and in terms of overall cost-effectiveness. Achieving a balance among all these factors is the key to an efficient extrusion process. Different industries and applications may have different priorities and metrics for evaluating efficiency, so the specific criteria for efficiency can vary widely. In current research, the efficiency was computed by the strain of the extruded metal. Table 5 presents the results of the non-homogeneous and homogeneous strain, Furthermore, the efficiency of the extrusion process.

Table 5 homogeneous, non-homogeneous strain and extrusion efficiency

	Homogeneous strain	non-homogeneous strain			Total strain	Efficiency
Type of strain	ϵ_H	ϵ_L	ϵ_r	ϵ_c	ϵ_T	η
Value	0.9613	1.3862	0	0	1.2508	76%

3.2 affect preheating on the density

The preheating of materials can have an impact on density, but the effect varies depending on the specific material and the temperature to which it is preheated. In many industrial processes, such as casting, heat treatment, and powder metallurgy, the control of preheating is critical to achieving the desired material properties, including density. The specific impact of preheating on density will depend on the material, the temperature to which it is heated, and the subsequent cooling and processing steps. Figure 2 illustrates the density values for the group in which performed in the current research.

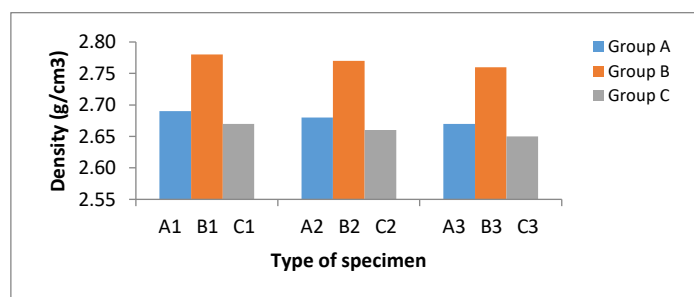


Figure 2 Density values

It's clear the density reduced, when the preheating temperature increased due to the grain size was increased. Also, when the preheating time increased, the density decreased. At a temperature of 450°C, the optimal condition is for the density to reach a favorable value of

2.78 g/cm³. This is due to the extrusion pressure process, which leads to smaller grain sizes. On the other hand, at a temperature of 400°C, the density value is 2.77 g/cm³ because the temperature does not exceed the annealing temperature. Consequently, the effect of pressing pressure is minimal and the grain size is larger. At a temperature of 500°C, the grain size is significantly increased due to excessive annealing, resulting in a lower density value of 2.76 g/cm³.

The correlation between temperature and density is contingent upon the nature of the substance. Typically, the density of a substance decreases when it is heated. The reason for this phenomenon is that increasing the temperature increases the kinetic energy and therefore the movement of the molecules that make up the substance. Consequently, this results in a widening of the distance between molecules, leading to a decrease in the substance's density.

3.3 affect preheating on the hardness

Preheating significantly impacts the hardness of materials, especially in heat treatment processes like annealing, tempering, and quenching. The exact effect of preheating varies depending on the material, the process, and the specific temperature to which it is heated beforehand. Preheating is a frequently used method in the annealing processes. The process entails raising the temperature of the substance to a precise degree, maintaining it at that level for a specified duration, and thereafter reducing the temperature gradually. Preheating is a crucial and frequently necessary stage in the hot extrusion procedure, since it can exert a substantial influence on the hardness of the material being extruded. Hot extrusion is the process of applying pressure to a heated metal or alloy, causing it to pass through a die and take on a desired shape or profile. Prior to extrusion, the material is commonly heated to a precise temperature in order to aid the deformation process. In the current research, nine specimens were performed to test the hardness values with different preheating temperatures and preheating times. Figure 3 shows the hardness values for the used specimens.

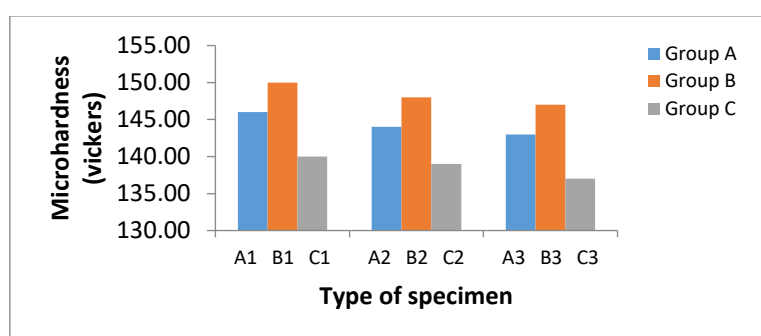


Figure 3 Hardness values for the used specimens.

From the results, it can be illustrated, If the preheating time increased, then the hardness value decreased. The decrease in the hardness value is due to the grain size being somewhat large. On the other hand, specimen B obtained the maximum hardness rating (150 Hv) as a result of being subjected to a temperature above its annealing point. Consequently, the pressing action had a significant impact on its value, resulting in a small grain size. Specimen A exhibits a reduced hardness value (146 Hv) due to being subjected to a temperature below the annealing point of aluminum metal. Consequently, the applied pressing pressure had a diminished effect. Specimen C obtained the lowest hardness value (140 Hv) because it was heated to a degree much higher than the annealing point value.

To summarize, preheating hot extrusion serves to improve the malleability of the material and make the extrusion process easier. The impact on hardness will be contingent upon various elements, such as the starting hardness of the material, the temperature at which it is preheated, and any future heat treatment procedures. Preheating can initially soften the material, but it can be followed by controlled cooling and heat treatment operations to provide the desired hardness in the final extruded product.

3.4 affect preheating on the tensile strength

Preheating can enhance the tensile strength of some materials. When materials are subjected to high temperatures, their atomic structure can undergo alterations, leading to the alleviation of internal stresses. This can lead to a more consistent and improved microstructure, hence enhancing the tensile strength. Preheating at certain temperatures is employed in certain heat treatment methods, such as solution heat treatment, to generate solid solutions in alloys. This procedure may improve material structural integrity and stretching resistance.

Under specific circumstances, preheating might result in a reduction of tensile strength. In operations such as annealing and tempering, the material is heated to alleviate internal tensions and encourage grain formation. As a result, the material may undergo a decrease in hardness and increased ductility, leading to a reduction in its tensile strength.

In order to attain the appropriate level of tensile strength, preheating is frequently conducted as a component of a regulated heat treatment procedure. The preheating temperature and duration are meticulously chosen to achieve a harmonious equilibrium between the intended mechanical attributes, such as tensile strength, and other material characteristics. Figure 4 illustrates the relationship between ultimate tensile strength and the specimens.

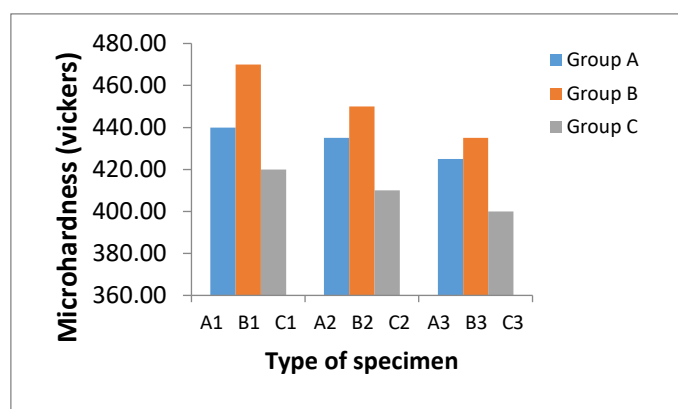


Figure 4 Ultimate tensile strength against the specimens

3.5 Microstructure of specimen

The microstructure of a material refers to the arrangement and characteristics of its internal crystalline or non-crystalline structure at a microscopic level. The microstructure of a specimen is typically examined under a microscope or through various materials analysis techniques. Figure 5 shows the micro structure.

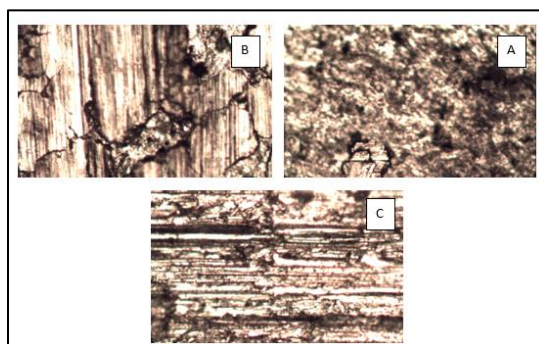


Figure 5 Specimens micro structure. (A: 400°C, B: 450°C, C: 500°C)

Conclusion

Ultimately, the mechanical characteristics of materials undergoing hot extrusion are greatly impacted by many process parameters such as temperature, extrusion velocity, and die configuration. Hot extrusion is a manufacturing technique where a hot material is pushed through a die to form intricate forms and profiles. The hot extrusion process impacts several crucial mechanical properties:

- 1- The hot extrusion process was successful with 76 % efficiency.
- 2- The optimum condition for preheating temperature and time are 450°C, 0.5 h respectively.
- 3- As the level of preheating intensifies, the density diminishes.

ACKNOWLEDGEMENT

I'd like to thank the Technical Institute in Nasiriyah / Southern Technical University / Iraq lab technicians for helping me finish this study.

REFERENCES

- [1] Justyna Wilin'ska, Artur Turek (2023), Hot Melt Extrusion as a Formulation Method of Terpolymer Rods with Aripiprazole: A Preliminary Study, *Appl. Sci.* 2023, 13, 9521. <https://doi.org/10.3390/app13179521>.
- [2] Stefanus Harj, Wu Gong (2023), Effect of Extrusion Ratio in Hot-Extrusion on Kink Deformation during Compressive Deformation in an μ Mg/LPSO Dual-Phase Magnesium Alloy Monitored by In Situ Neutron Diffraction, *Materials Transactions, Japan Institute of Metals and Materials*. <https://DOI: 10.2320/matertrans.MT-MD2022004>.
- [3] Ryohei Kobayashi, Tatsuya Funazuka (2023), Effects of Hot Extrusion Temperature Conditions on the Hardness and Electrical Conductivity of Rapidly Solidified Al-Fe Alloys, *MDPI, Materials* 2023, 16, 5050. <https://doi.org/10.3390/ma16145050>.
- [4] Leilei Zhao , Kecheng Zhou (2022), Experimental and Numerical Study on Friction and Wear Performance of Hot Extrusion Die Materials, *Materials* 2022, 15, 1798. <https://doi.org/10.3390/ma15051798>.
- [5] A.S.MAHDi, M. S. Mustapa (2016), EFFECT OF COMPACTION PRESSURE ON MECHANICAL PROPERTIES OF ALUMINIUM PARTICLE SIZES AA6061A1

ALLOY THROUGH POWDER METALLURGICAL PROCESS, ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 8, APRIL 2016.

- [6] Sami Al-Alimi, Mohd Amri Lajis (2021), hot extrusion followed by a hot ecap consolidation combined technique in the production of boron carbide (b₄c) reinforced with aluminium chips (AA6061) composite, *materiali in tehnologije / materials and technology* 55 (2021) 3, 347–354, doi:10.17222/mit.2020.177.
- [7] A. S. Mahdi, M. Sukri M., M. A. lajis (2016), THE EFFECT OF COLD COMPACTING PARAMETERS FOR PRODUCING RECYCLES ALUMINIUM BY MILLING PROCESS, ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 10, MAY 2016
- [8] K. AIZAWA , T.KAWASAKI, (2023), Strengthening of α Mg and long-period stacking ordered phases in a Mg-Zn-Y alloy by hot-extrusion with low extrusion ratio, *Acta Materialia* 255 (2023) 119029, <https://doi.org/10.1016/j.actamat.2023.119029>.
- [9] Qinghang Wang, Haowei Zhai (2022), Hot-deformation kinetics analysis and extrusion parameter optimization of a dilute rare-earth free magnesium alloy, *Journal of Magnesium and Alloys*, m5+; September 28, 2022, <https://doi.org/10.1016/j.jma.2022.07.013>.
- [10] Vidhish Naik, Nayaka Narasaiah (2022), Hot-extrusion behavior of biodegradable Zn-Mg alloys, *Materials today*, December 2021, *Materials Today Proceedings* 56(1), DOI:10.1016/j.matpr.2021.12.023
- [11] A.S.MAHDi, M. S. Mustapa (2016), EFFECT OF SINTERING TEMPERATURE ON COMPRESSION STRENGTH AND MCROHARDNESS OF RECYCLING ALUMINIUM ALLOY AA6061 THROUGH BALL MILL PROCESS, ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 1.
- [12] Sami Al-Alimi¹, Mohd Amri Lajis, (2021), hot extrusion followed by a hot ecap consolidation combined technique in the production of boron carbide (b₄c) reinforced with aluminium chips (aa6061) composite, *Materials and technology* 55 (2021) 3, 347–354. DOI: 10.17222/mit.2020.177
- [13] A. S. Mahdi, M. S. Mustapa (2016), effect of sintering temperature on compression strength and microhardness of recycling aluminum alloy aa6061 through ball mill process, ARPN journal of engineering and applied sciences, vol. 11, no. 1, January 2016.
- [14] Y Q GUO, J H CUI, L D PAN and S LI (2022), Key technologies of cooling and lubrication for closed hot extrusion automatic production line, *IOP Conf. Series: Materials Science and Engineering*, 1270 (2022) 012028, doi:10.1088/1757-899X/1270/1/012028.
- [15] H. Delavar, M. Kasaeian (2023), Hot deformation behavior and processing map development of Mg/Al₂O₃ composite: A case study of extrusion ratio effects, *Journal of Materials: Design and Applications* (2023), <https://doi.org/10.1177/14644207231178612>.
- [16] Mosa Almutahhar, Ali Alhajeri (2023), Prediction of tool failure in metal hot extrusion process using artificial neural networks, *Materials Research Proceedings* 36 (2023) 8-15, <https://doi.org/10.21741/9781644902790-2>.

- [17] Wenhui Sun and Cuiping Yang (2023), Simulation of Cross Wedge Rolling and Hot Extrusion-Combined Forming Process for Axle Sleeve, Metals, MDPI, 2023, 13, 1017. <https://doi.org/10.3390/met13061017>.