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RESEARCH ARTICLE - ENGINEERING

Joining of Polymer to Aluminum Alloy AA1050 By Friction Spot Welding

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Abstract

The friction spot welding process is used to join the hybrid joint of aluminium to polymer. AA 1050 Aluminum alloy and polyethylene polymer (type of plastic) were used for joining. Aluminium surface treatment was done to increase the wettability of it. The surface treatment was done by electrochemical treatment. Two parameters of the joining process were used: (1, 1.5 and 2) min. (920, 1340 and 1500) rpm for time and rotational speed, respectively. Many tests for the joint are done: shear test and Scanning electron microscopy (SEM). Using the Minitab program, the effect of the parameters on the joint was analysed. The maximum value of the shear force was (1587 N) at 1.5 min. time and 1340 rpm rotational speed. The minimum shear force was (589 N) at 1 min. time and 920 rpm rotational speed. The joints which were tested failed by an interfacial shear with a ductile fracture of the polymer side. The process of joining mechanism occurred through a mechanical interlocking between the molten polymer and the surface of the AA 1050 aluminium specimen, cohesive and adhesive. The average thickness for the joint of the tested specimens was 4µm.

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Keywords: Friction Spot Welding (FSW); Polymer; AA1050.

1. Introduction

The friction spot welding process is one of the many types of hybrid joining. So, it is very suitable for joining Aluminum to polymer due to the increasing necessity of hybrid joining. The treatment of the surface of the aluminium should be done to increase the wettability of it. Hybrid joining of materials is very important because it provides many properties which aren't found in one material [1]. Hybrid joining is necessary to produce a lightweight of dissimilar materials having high strength, corrosion resistance, toughness and conductivity [2]. Many kinds of joining processes depend upon the different mechanical and physical characteristics between the polymer and the metal, which are bonded: adhesive bonding, laser direct joining, hot press bonding process, injection clinching joining, ultrasonic staking and friction spot welding [3-9]. Friction Spot welding is used for joining similar and dissimilar materials [10]. The process of joining metallic to polymeric materials (dissimilar joining) has many important applications [11]. One of the many important applications in aerospace, automobile engineering structures and medical and biological industry [12]. Hybrid joints exhibited combined chemical, physical and mechanical properties between the polymers and the joined metal [13]. polymers and Metals are mechanically joined with chemically bonded adhesives and \ or mechanical interlocks. So, to improve the strength, surface roughness should be considered due to the density and size of the surface roughness and the depth and size of pores on the metal surface [14].

An SCF/PEEK (Short carbon fiber reinforced poly ether ketone) and AA 2060-T8 (aluminium alloy) joined by friction stir welding and with co-controlling performance and shape, the chemical bonding and the mechanical interlocking refer to the main mechanisms of bonding [15]. It was stated that the bonding mechanism was mechanical interlocking in the polymer-to-metal joining of the hybrid bonds. Therefore, it is important to know how to increase and improve the joint quality and mechanical interlocking [16]. Carried out an interlayer between the two materials, which are joined to the interlayer material, is also incorporated into the joint material produced by the RFSSW tool [17].

The investigation of this research is to optimise the pre-treatment of the surface of aluminium alloy AA1050 to be joined to polyethylene polymer by the friction spot welding process. Therefore, due to the electrochemical treatment of the surface, the strength is little compared to another process of joining and treatment. A method of Design of the experiment was used to analyse the results of experiments and discuss the effect of the friction spot welding process parameters on the shear force of the joint and to optimise the process parameters. Also, the optimum parameter of joining was analysed by scanning electron microscope (SEM).

Nomenclature & Symbols

AA	Aluminium alloy	SEM	Scanning Electron Microscope
FSW	Friction Spot Welding	RFSSW	Refill Friction Stir Spot Welding
PE	Polyethylene	DC	Direct Current
DOE	Design of experimental	rpm	Revolution Per Minute

2. Experimental Setup

2.1. Materials

The process is used as FSW (friction spot welding process) and also was used to connect two types of materials: aluminium alloy AA1050 with polyethylene (PE). The aluminium alloy's chemical composition and mechanical properties are illustrated in Tables 1 and 2, respectively; the polyethylene had a melting point of Tm=128°C.

Table 1. Chemical composition of AA1050

Property / Material	Si	Fe	Cu	Mn	Mg	Zn	Ti	Balance Al
Standard ratio of AA1050	0.25	0.40	0.05	0.05	0.05	0.07	0.05	99.5
Percentage of sample tested	0.0554	0.93	0.0035	0.0037	0.0011	0.001	0.0179	< 99.5

Table 2. Mechanical properties of AA1050

Property / Material	Yield Point σu, (MPa)	Tensile Strength σ y, (MPa)	Elongation EL%
Standard ratio of AA1050	103	110	10
Results of sample tested	109	128	17

2.2. Specimens' preparation

A 3 mm specimen thickness for AA1050 and polymer (PE) were used for joining, respectively. According to the acceptance criteria of standard specification (AWS spot welding C1.1M/C1.1:2012). Nine specimens were manufactured with a length of 100mm and a width of 25mm, while the lap joint dimensions were 25 x 25 mm^2 [18]. Fig. 1 illustrates the sample schematic, which can be joined with dimension.

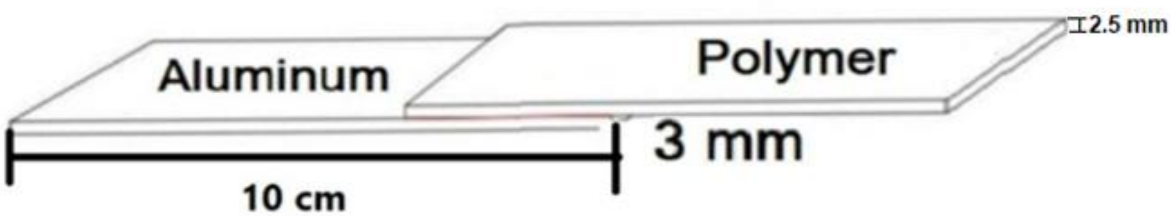

Fig. 1. Schematic of Aluminum alloy/ Polyethylene (polymer) with lap joint of 25 X 25 mm^2

2.3. Joining process and friction spot welding process

The aluminium surface should be treated to obtain a good hybrid aluminium joint to polymer. Also, the process which was used to treat the surface was electrochemical treatment. the specimen was put in the liquid (distilled water) in a glass beaker and passed a DC current from a power supply the anode was connected to the aluminium, but the cathode was connected to the lead piece. The current passed through the circuit was (6A), and the voltage was (10 volts), as shown in Fig. 2.

The process of joining was taken place by a drilling machine using a tool as shown in Fig. 3. The heat was generated by rotating the tool over the fixed specimen through a variable time. Time (1, 1.5 and 2 min.) and rotational speed (920, 1340 and 1500 rpm) were Parameters.

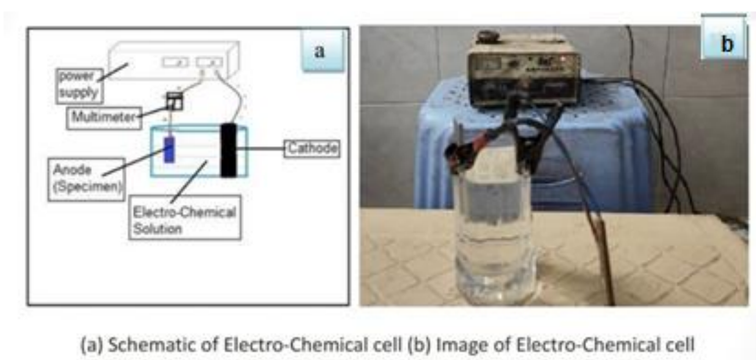

Fig. 2. Schematic and image of Electro-chemical rig

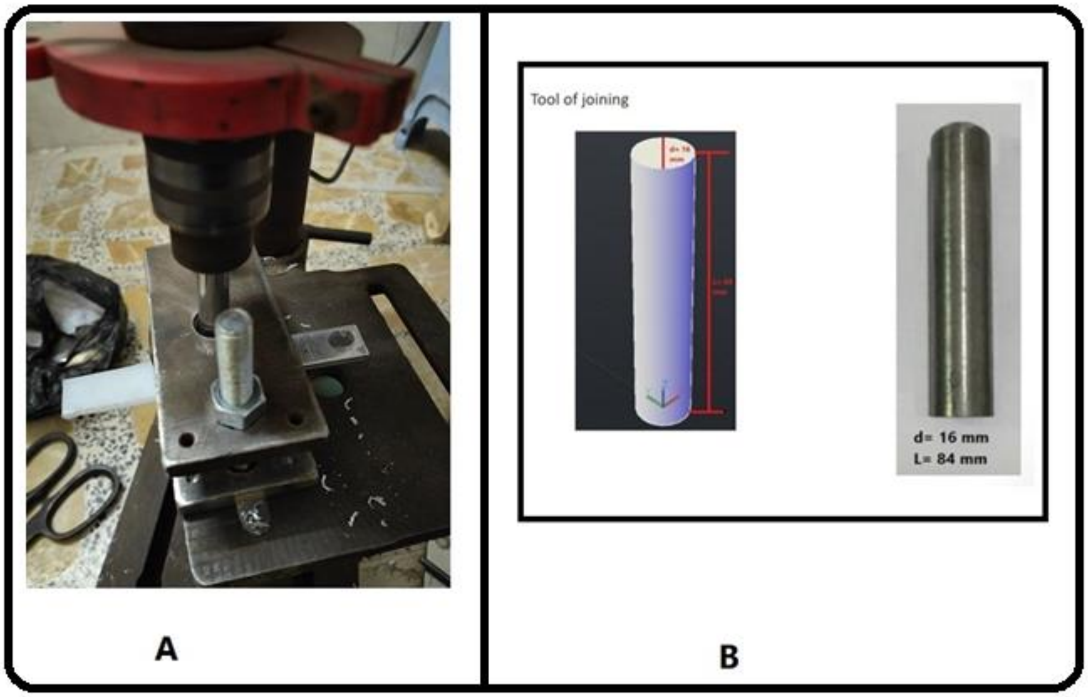

Fig. 3. Friction spot welding; A) Picture of friction spot welding process, and B) Tool of joining process

2.4. Design of experimental (DOE)

The design of the experimental method (DOE) was utilised according to the Taguchi Approach to study and analyse the effects of the parameters of the friction spot welding process on the welded joint quality. The rotational speed and processing time are the most important parameters that directly affect the shear force amount of the joint. A three-count of the parameters was used to investigate the joint shear force, illustrated in Table 3. Taguchi method was applied with an L9 orthogonal array to design experiments. six experiments were designed according to the Taguchi method with respect to the levels of each parameter, as illustrated in Table 3. The specimens that were joined are shown in Fig. 4.

2.5. Experimental tests

A SEM (scanning electron microscope) inspection and the shear test were used to test the connected specimens. The joining process was according to the standard “AWS spot welding C1.1M/C1.1:2012” to prepare and examine the tensile shear test specimens [18]. Two shims were used at the ends of each joined specimen on the opposite sides, as in Fig. 5. to prevent bending and slipping during the tensile test, A 10 mm/minute is the cross-head velocity of the tensile shear test. A (SEM) inspections, the specimens were dealing with wet grinding emery papers using SiC with different grits size p (180, 360, 600, 800, 1200 and 2000), so the process was done according to the standard ASTM E 407- 99 [19]. The polishing process was done with different sizes of alumina particles (3, 0.3, and 0.05) µm. A special cloth of polishing was used at (180 RPM). The mirror surface was obtained by washing with water and alcohol, respectively; hence, the joined specimens were dried with air. The (SEM) test was used to examine and inspect the joint cross-section's microstructure and indicate the joint's interface.

Table 3. Joint parameters according to the Taguchi method

Sample No.	Time (min)	Rotation speed(rpm)
S1	1	920
S2	1.5	920
S3	2	920
S4	1	1340
S5	1.5	1340
S6	2	1340
S7	1	1500
S8	1.5	1500
S9	2	1500

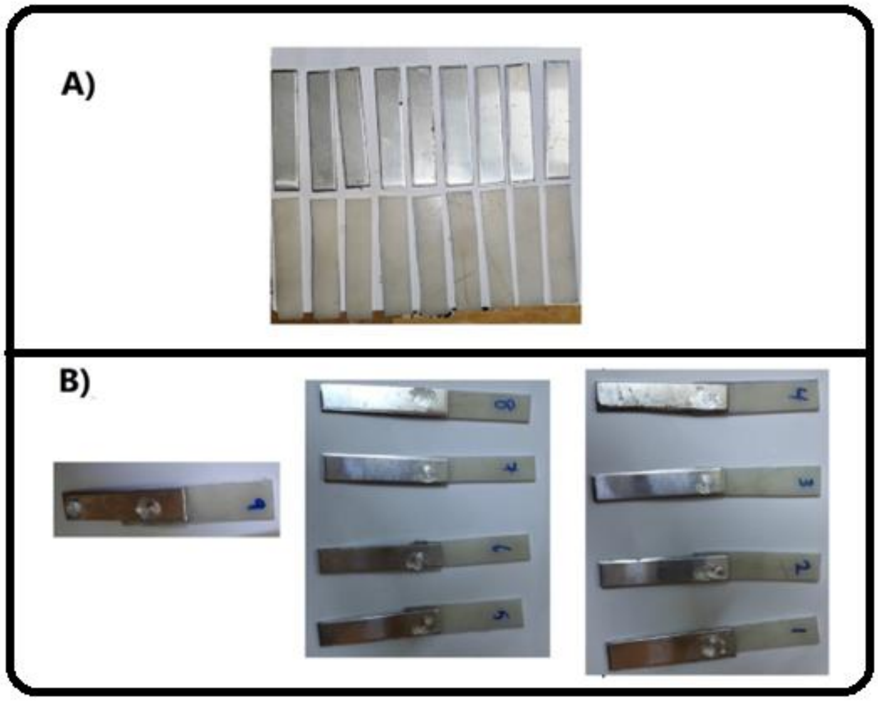

Fig. 4. Experimental joint specimens of PE-AL; A) before joining, and B) after joining

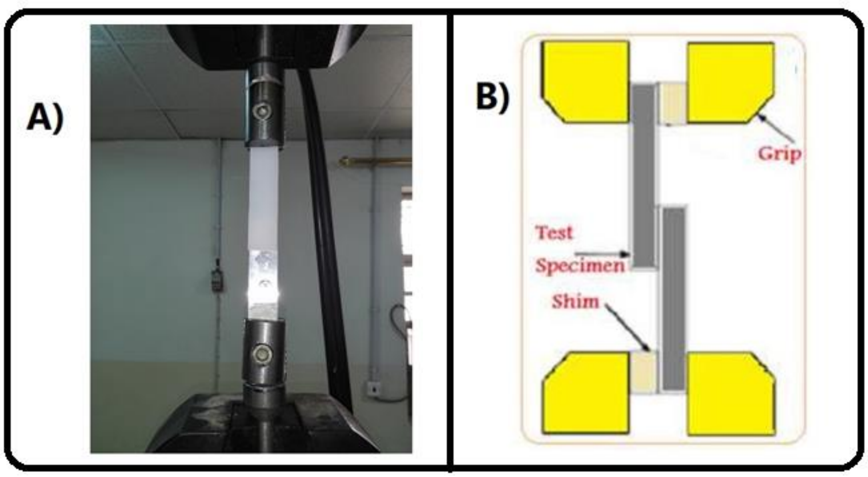

Fig. 5. The shear test equipment: a) Experimental equipment shear test & b) schematic of the shear test

3. Results and Discussion

3.1. Shear Test

The specimens joined by the friction spot welding were successfully joined and tested by shear test equipment. The shear test result is indicated in Fig. 6. Sample number 4 has the maximum shear force of 1587 N. The parameters of sample 4 are 1 min. as time and 1340 rpm as a rotational speed. The minimum shear force was for the sample number 1 and was 589N. The parameters of sample 1 are 1 min. as time and 920 rpm as the rotational speed. The shear force of the samples which be joined was increased by increasing the rotational speed from 920rpm to 1340rpm but decreased at 1500rpm. The processing time at 1min. was a good parameter to increase joint strength.

3.2. DOE (The Main Effect Plot)

By using the Taguchi analysis method, the shear force was analysed by the Minitab program to study the effect of parameters of joining on the strength of the joint and obtain the optimal level of parameters. The better shear force is given by this method. Fig. 7 shows the effect of time and rotational speed on the joint strength. Increasing the processing time from 1min. to 1.5min. will increase the shear force (joint strength) but decrease at 2min. Also, the rotational speed of the tool when increased from 920rpm to 1340rpm the joint strength increased, but the continued increase of rotational speed to 1500rpm decreased the shear force (joint strength).

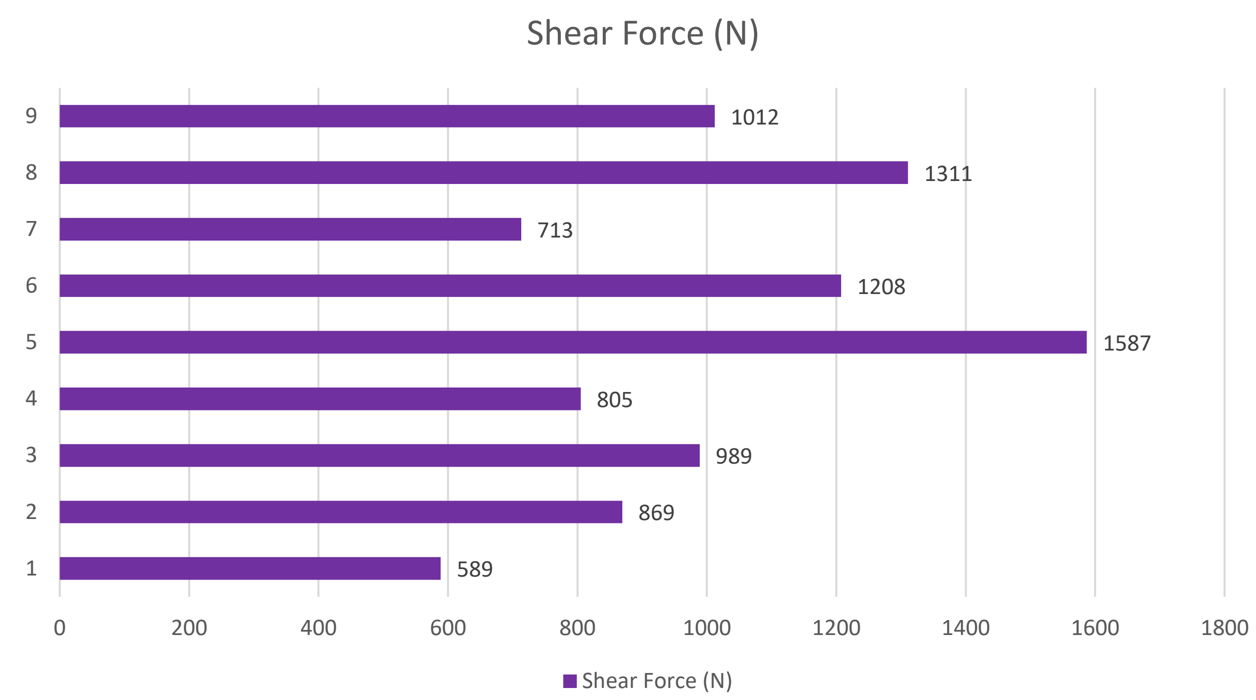

Fig. 6. Shear force results of all samples

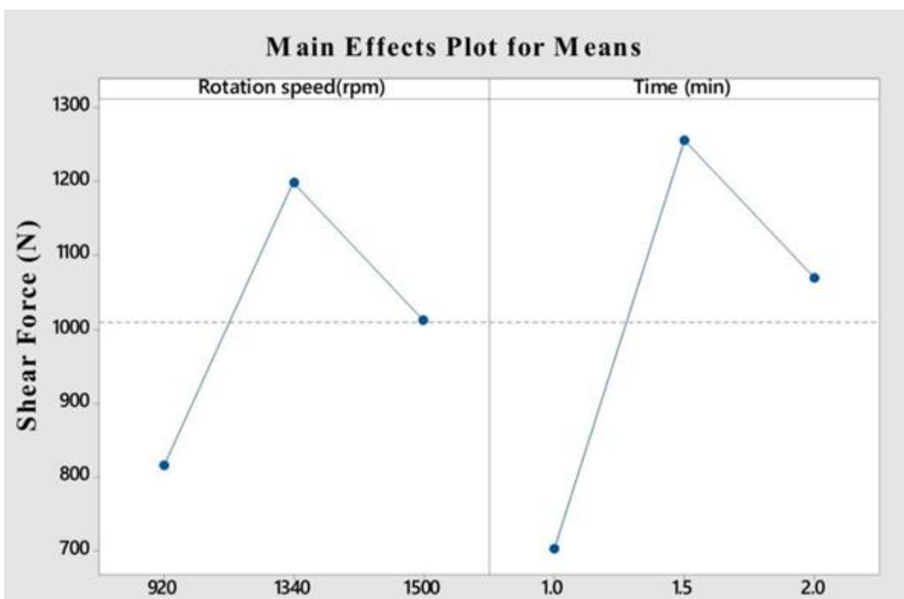

Fig. 7. Main effect plot for the process parameters and its effect on tensile shear force

3.3. Scanning electron microscope (SEM) inspections

The sample, which had an optimum shear force, No.5, was inspected and examined by SEM inspections to analyse the interface type between the two-hybrid materials, AA1050 and polyethylene. Fig. 8 shows the cross-section of macro-structural zones of the joint, which included the base materials and resolidified polyethylene over the treated surface of metals. The SEM test was performed to indicate the thickness of the interface layer (mechanical interlocking) between the two materials that determine the behaviour of the joining mechanism at the interface line. The width of the line interface was varied along the aluminium surface with an approximate range of 4-6μm, representing a good interface width [20]. The SEM image indicated that the interface between the aluminium and re-solidified polyethylene occurred with a mechanical interlock between the two materials. The adhesive was achieved between the molten polymer (HDPE) layers and the electrochemical surface of AA1050 with a mechanical interlock through the porous aluminum surface.

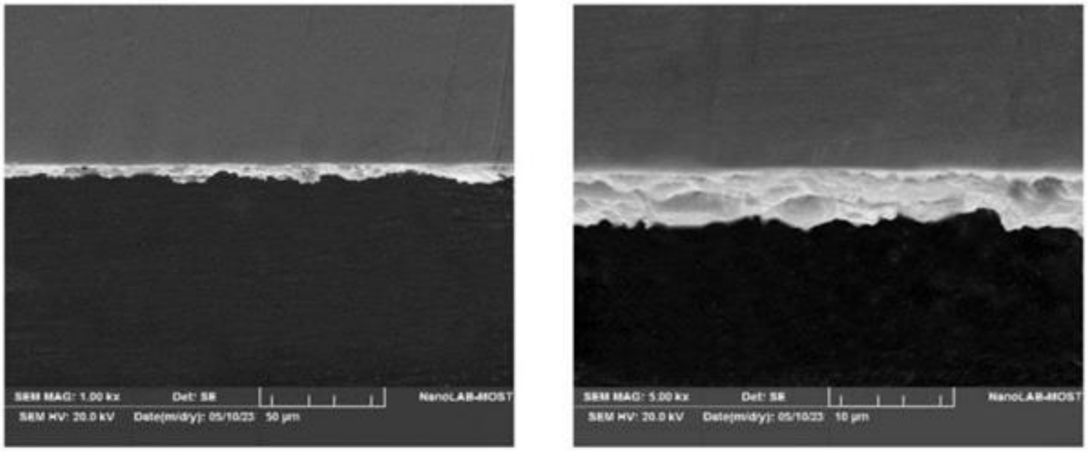

Fig. 8. SEM images of the joint area for sample 5

4. Conclusions

A friction spot welding process was utilised to join the aluminium alloy of AA1050 with polyethylene (PE). A surface treatment of aluminium was obtained. The effect of time and rotational speed of the process on the joint strength (shear force) was studied. The following conclusions were recorded:

- The friction spot welding is a successful method to join the AA1050 to PE.
- The maximum shear force of the joint (1587N) occurred at 1.5 min. and 1340 rpm.
- The minimum shear force of the joint (589N) occurred at 1 min. and 920 rpm.
- The heat input rate and/or the applied pressure of the tool had the highest influence on the joint mode of failure and shear force value (joint strength).
- The SEM inspection examined the joint and indicated that the joining mechanism occurred by a mechanical interlock between the two materials and adhesive.
- The line width of the interface of the joint had a range of 4-6μm.

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