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OPTIMIZATION AND EVALUATION OF AGEING PARAMETERS ON MECHANICAL PROPERTIES OF AA 6061AND AA 5154 WELDED JOINTS USING TAGUCHI METHOD

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ABSTRACT
This present paper is an experimental study aiming to optimize the welding process parameters and ageing parameters to improvise the outcome of ultimate tensile strength and hardness on welded joint interface of dissimilar materials. In order to evaluate these parameters suitable heat treatment parameters like solutionizing and Artificial ageing methods are considered with different elevated temperature - time conditioning with suitable welding parameters like current, voltage, welding speed, Inert gas, to observe the change in behavior before and after heat treatments of welded joints and to find the optimized and best suited variables to manufacture a sound welded joint an statistical approach like Taguchi methodology is employed. It is found that by means of an appropriate selection of age hardening parameters, it is possible to achieve a better understanding of joining of TIG welded AA 6061 and AA 5154 aluminium alloy.

Keywords: Gas Tungsten Arc Welding, Aluminum AA 6061, AA 5154, dissimilar materials, Inert gas, solutionizing, Age hardening, Taguchi method, ultimate tensile strength (UTS), Hardness.

I. INTRODUCTION
In theory, one of the simplest traditions of joining two metal surfaces is to stream the high voltage electric current to melt the metal pieces to be joined and allowing it to solidify to produce the desired strength welded joints. There are considerable advantages to be gained from such a process. There is no high immensity of melting, buckle is minimized, and the thermal cycle will be relatively less. Due to these advantages there always an essential requirement that must be met if a satisfactory joint is to be made in this way. Firstly, the temperature of the solid at the solid-liquid interface must be at least equal to the melting point of the liquid. Secondly, there must be some means of removing the oxide film on the surface of the solid so that the liquid can bond to a clean metal surface to obtain a desired strength of the welded joints.

II. PRODUCTION OF ALUMINUM THROUGH EXTRUSION
The initial step in aluminum extrusion is the preparation of the aluminum alloy. The aluminum begins as cast logs or billets. The aluminum is melted in a furnace then transferred to a gravity fed casting system. As the liquid aluminum cools, crystals begin to nucleate via heterogeneous nucleation. As the temperature is lowered, the crystals begin to grow and impinge on each other to form grains. The alloying elements are forced along the grain boundaries. From their aluminum get heat treated to homogenize the cast logs due to this the alloying elements diffused out of grain boundaries and improves extrudability and gives better surface finish. Even though it has the necessary properties it may be affected due to heat produced by joining of metals with welding process.

III. PRECIPITATION HARDENING (AGE HARDENING)
The final strength of the aluminum alloy is controlled by the aging process. Precipitation hardening is when precipitates in the alloy impede the movement of dislocations within the crystal lattice. Precipitates grow in size resulting in a stronger material. This growth can occur at room temperature, but may require long periods of time to achieve the desired precipitation size. Artificial aging is a process where an extruded profile is placed in an oven around 350°F, expediting the growth of precipitates and producing a measurable increase in strength.

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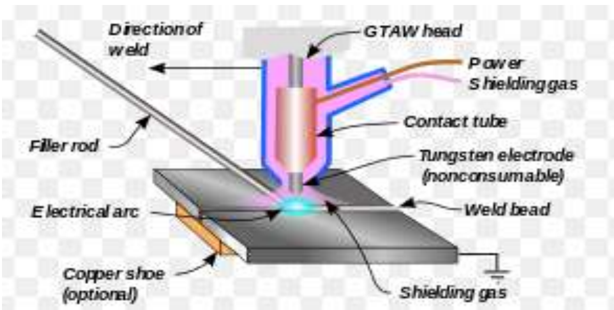
IV. LITERATURE REVIEW

In general when fusion welding is done pure aluminum or any of the annealed non-heat treatable alloys made with filler rod or electrodes of matching composition have strength almost equal to that of the parent metal. When work-hardened plate is welded, the heat-affected zone may be fully or partly annealed, thus irreversibly reducing the tensile strength. This reduction can be reduced by using the gas tungsten arc process (GTAW) with Helium shielding and polarity with electrode negative, which reduces the width of the heat-affected zone. The strength of heat-treatable aluminum alloys is obtained by solution treatment followed by quenching and then ageing, either at room temperature or, more usually, at elevated temperature. During the ageing treatment, the hardness and tensile strength increase because of precipitation and the formation of locally strained regions associated with the formation of clusters of solute atoms. [1]. Owing to their easier applicability and better economy, gas tungsten arc welding is frequently employed to weld aluminum alloys [2-3]. The strengthening mechanism of any aluminum alloy can be explained in terms of obstacles to the motion of dislocation by the formation of strengthening precipitates, which should be fine enough [4]. As a result, the loss of joint strength is attributed to the dissolution of strengthening precipitates and the formation of large columnar grains during welding process [5, 6]. It was reported that the joint strength is only about 40% of the parent alloy in T87 condition [7]. To overcome this shortcoming, a post weld heat treatment (PWHT) process is proposed to improve the microstructure and mechanical properties of the welded joint of aluminum alloy [8].

A number of research works have investigated the application of PWHT to welding joints of aluminum alloys using several welding processes. The effects of a post weld aging treatment on the tensile properties of argon arc welded AA7075 aluminum alloy were studied in Ref. [9], and it was found that the enhancement in strength reached 10%. The strengthening behavior was associated with the appreciable changes in the formation and distribution of precipitates, as pointed out by M. Temmar and et al [10]. J. Staley et.al had studied Advances in aluminum alloy products for structural applications in transportation and other applications.

V. GAS TUNGSTEN ARC WELDING (GTAW)

Welding is a joining of two similar or dissimilar materials by application of fusion. Gas tungsten arc welding process is one such process which has an ease to welding without defects.



During this welding process the common heat-treatable base alloys, such as 6061-T6 and AA 5154 (work piece), lose a substantial amount of their mechanical strength after welding. For example, T6 temper 6061 has an ultimate tensile strength of at least 290 MPa (42,000 psi) and yield strength of at least 240 MPa (35,000 psi). In the present circumstance to perform at the required mechanical strength post - weld heat treatment is done. Next is the necessity to choose and consider the filler alloys because the most normally used filler materials will not react to post-weld heat treatment because of inadequate integration with the heat-treatable base material. This is not always easy to achieve and can be complicated to control consistently.

On this basis, filler alloys which can act in response separately to heat treatment are needed to consider. For such parameters filler alloy 4643 (filler material), was particularly considered for welding 6xxx sequence base alloys and producing elevated mechanical property in the post-weld heat-treatment condition is used during this investigation. It is mainly developed by reducing the silicon in the well-known alloy 4043 and adding 0.10 percent to 0.30 percent magnesium.

Productively choosing the finest filler alloy can be achieved only after a fully testing of different variables connected with welding aluminum components and their applications. In view of this the type of the base

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material to be welded 4643 filler alloy had been used to investigate its effects on before and after heat treatments at welded joint interface.

VI. EXPERIMENTAL DETAILS

Gas Tungsten Arc Welding (GTAW) has been used to produce a butt joint of AA 6061 and AA 5154 of sizes 200 X 60 X 6 mm^3 each. The filler material 4643 is used as an electrode material. A set of L9 orthogonal array is used to conduct experiment designed by Taguchi method.

The experiments were arranged in three levels with three parameters viz., Welding current, Welding voltage, Welding speed, and Helium gas is used as shielding gas which is constant for all experiments.
The parameters selected for welding are:

Table 1: Experimental welding parameters

Factor	Parameters	Parametric Values
1	Welding current (Amp)	100, 150, 200
2	Welding voltage (V)	10, 15 ,20
3	Welding speed (mm/min)	100, 125, 150
4	Shielding Gas	Helium (Constant)

- Properties of Work-piece material AA 6061 and AA 5154 respectively.

Material : AA 6061 Properties					
Element	Cu	Mg	Si	Cr	Al
Wt%	0.25	1.0	0.6	0.25	Balance
Material : AA 5154 Properties					
Element	Cu	Mg	Si	Cr	Al
Wt%	0.1	3	0.25	0.35	Balance

- Properties of Filler material 4643 :

Element	Si	Fe	Cu	Mn	Mg	Zn
Wt%	3- 4	0.8	0.10	0.05	0.1-0.3	0.1

The weld joints has been welded at different level of welding current, voltage and speeds with helium as shielding gas and are mechanically tested for ultimate tensile strength using Universal testing machine and hardness using Rockwell Hardness Testing Machine. The tensile specimen is prepared with ASTM E-08 Standards as shown Figure 2 represents the standard work pieces before testing.

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Figure (2): Shows (a) tensile test specimen(b) Hardness test specimen

Table 2 Describes the results obtained for tensile strength and hardness tests at various welding conditions.

Welding Parameters			**Results**	
Current (Amp)	**Voltage (V)**	**Speed (mm/min)**	**Ultimate tensile strength (MPa)**	**Hardness (RB)**
100	10	100	240.2	65
100	15	125	275.6	69
100	20	150	267.9	70
150	10	125	291.9	68
150	15	150	245.9	66
150	20	100	271.1	69
200	10	150	279.6	74
200	15	100	301.3	72
200	20	125	269.8	67

VII. DATA ANALYSIS FOR WELDING PARAMETERS

In this study, all the analysis based on the Taguchi method is done by Taguchi DOE software (Quality- 4) to determine the main effects of the process parameters, to perform the analysis of variance (ANOVA) and to establish the optimum conditions.

Table 3: Shows response table for signal to noise ratio for hardness.

Level	Welding Current	Welding Voltage	Welding Speed
1	39.37	39.50	39.46
2	39.35	39.51	39.41
3	39.76	39.47	39.61
Delta	0.41	0.04	0.20
Rank	1	3	2

Table 4: Shows analysis of variance test for hardness

Welding Current	DF	Adj SS	Adj MS	F-Value	P-Value
CURRENT	2	20.2222	10.1111	0.53	0.654
VOLTAGE	2	0.2222	0.1111	0.01	0.994
SPEED	2	6.2222	3.1111	0.16	0.860
Error	2	38.2222	19.1111		
Total	8	64.8889			

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From the results obtained from ANOVA software the delta value which indicate difference between highest and lowest average value for each factor is maximum for welding current and hence Rank 1 is given to it & rank 2 to the second highest delta value is given to speed. Welding voltage given least delta value.

From above table F value in ANOVA is used to find out the means between two populations are significantly different. Hence F value for current is maximum (0.53) and minimum for voltage.

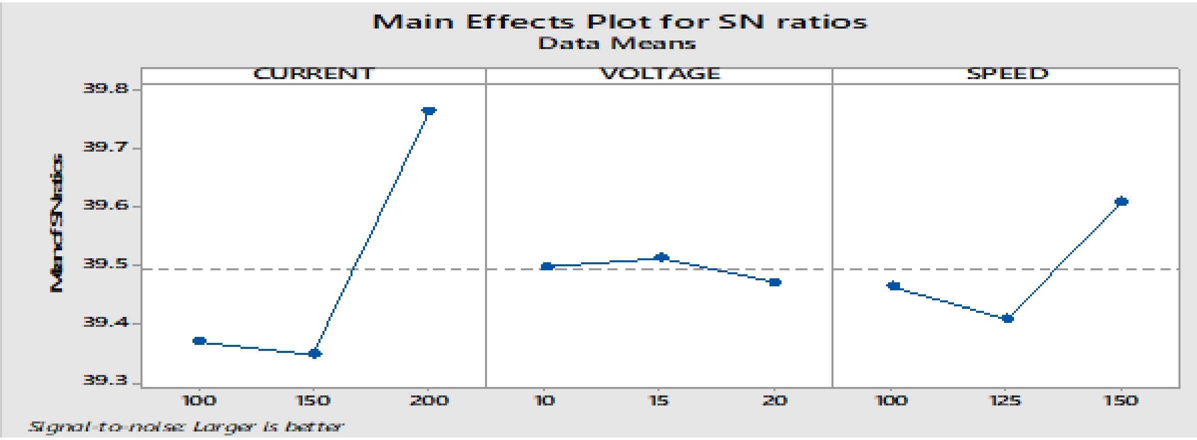
P value in table indicates that which parameters significantly effects on response value. I.e. for any parameter if P value less From the results obtained from ANOVA software the delta value which indicate difference between highest and lowest average value for each factor is maximum for welding current and hence Rank 1 is given to it & rank 2 to the second highest delta value is given to speed. Welding voltage given least delta value.

From above table F value in ANOVA is used to find out the means between two populations are significantly different. Hence F value for current is maximum (0.53) and minimum for voltage. P value in table indicates that which parameters significantly effects on response value. I.e. for any parameter if P value less than 0.005 which affects most, welding current is considered as mostly effecting parameter on hardness.

Level	Welding Current	Welding Voltage	Welding Speed
1	164.6	169.8	169.8
2	168.6	171.6	173.5
3	177.3	169.1	167.2
Delta	12.7	2.5	6.3
Rank	1	3	2

From the below graph we can conclude that hardness varies linearly from 100 amps to 150 amps then it suddenly increased to maximum value at 200 amps. Voltage doesn't affect much on hardness hence it is approx. constant. With increasing speed from 100 mm/min to 125 mm/min hardness decreased and increased to maximum at 150 mm/min.

From below graph we can conclude that UTS varies with current which increases with increase in current and is maximum when the current value taken as 200 amp and minimum at 100 amp. For voltage when we take 15 volts gives maximum UTS. Ultimate tensile strength first increases linearly to maximum value at speed of 125 mm/s and then decreased.



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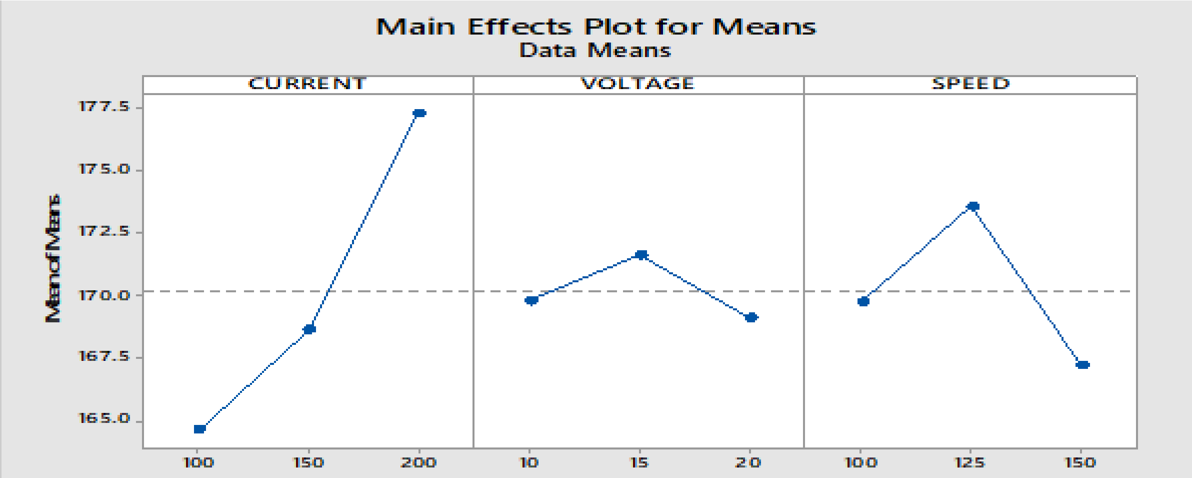

Table 5: Represents ANOVA for UTS

Source	DF	Adj SS	Adj MS	F-value	P-value
Current	2	763.85	381.92	0.40	0.715
Voltage	2	36.78	18.39	0.02	0.981
Speed	2	323.01	161.50	0.17	0.856
Error	2	1914.13	957.06		
Total	8	3037.76			

From the above Table of ANOVA the delta value indicates difference between highest and lowest average value for each factor. Rank 1 is given to highest delta value that is welding current rank 2 to the second highest, and so on, to indicate the relative effect of each factor on response. Hence current, welding speed have most effect on ultimate tensile strength hence is given by first and second ranks. Voltage is least effect on hardness and hence given last rank. From above table F value in ANOVA is used to find out the means between two populations are significantly different. Hence F value for current is maximum (0.40) and minimum for voltage. P value in table indicates that which parameters significantly effects on response value. i.e., for any parameter if P value less than 0.005 which effects most, welding current is considered as mostly effecting parameter on UTS.

VIII. DATA ANALYSIS FOR HEAT TREATMENT PARAMETERS

Table 6: Represents results after Heat treatment

Solutionizing Temperature (ºC)	Solutionizing Time (Hrs)	Ageing Temp (ºC)	Ageing Time (Hrs)	Ultimate Tensile Strength (MPa)	Hardness (RB)
500	0.5	180	6	252.8	81
500	1	200	12	282.1	87
500	1.5	250	18	285.4	74
530	0.5	200	18	298.9	70
530	1	250	6	255.8	83
530	1.5	180	12	301.1	89

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560	0.5	250	12	289.4	88
560	1	180	18	298.1	85
560	1.5	200	6	278.9	79

The Mechanical behavior of TIG welded 6061 aluminum alloy AA5154 under different aging conditions has been considered for different aging temperature, aging time and solutionizing time and solutionizing temperature using L9 orthogonal array to obtain optimum condition for hardness and ultimate tensile strength after post welded heat treatment (as shown in Table 6).

Table 7: Representing the response table for signal to noise ratio for hardness after heat treatment

Level	STEMP	STIME	ATEMP	ATIME
1	38.11	37.99	38.58	38.17
2	38.09	38.59	37.88	38.89
3	38.48	38.11	38.22	37.62
Delta	0.39	0.6	0.7	1.26
Rank	4	3	2	1

Table 8: Representing the response table for Means

Level	STEMP	STIME	ATEMP	ATIME
1	80.67	79.67	85	81
2	80.67	85	78.67	88
3	84	80.67	81.67	76.33
Delta	3.33	5.33	6.33	11.67
Rank	4	3	2	1

The below graph represents the main effects plot for hardness after heat treatments from this it is observed that as there is increase in solutionizing temperature there is decrease in hardness up to 530°C and as there is a sudden rise in hardness as the solutionizing temperature is increasing and the highest solutionizing temperature is observed to be for one hour. The Ageing temperature is observed to be the best at 180 °C at 12 hours of ageing time.

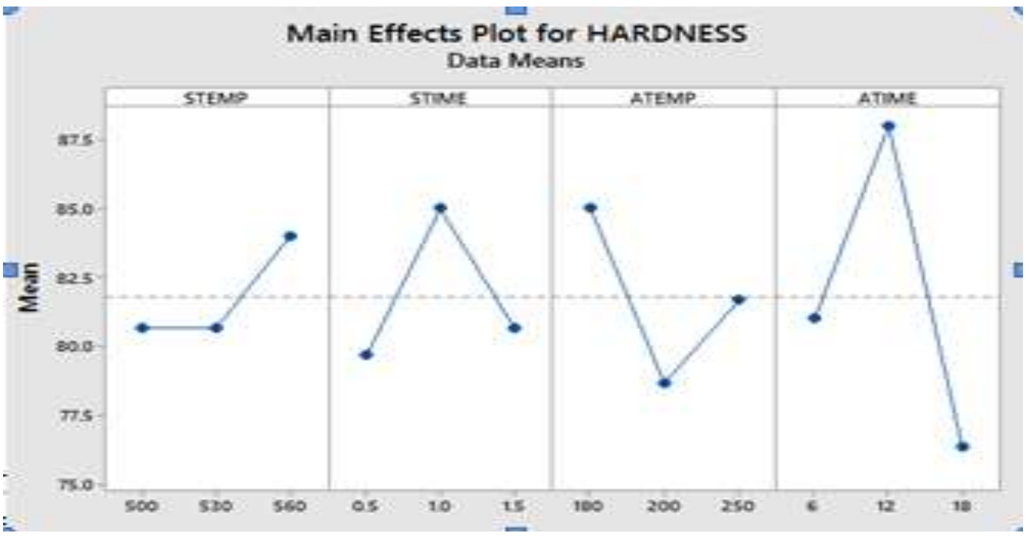

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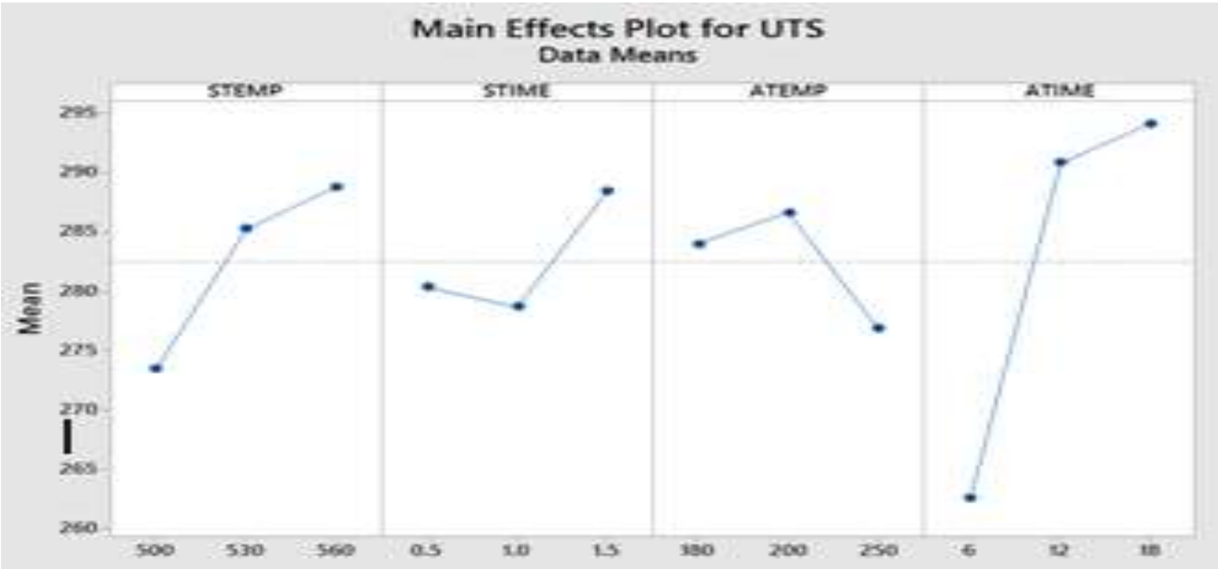
Table 9: Representing the response table for signal to noise ratio for UTS after heat treatment.

Level	STEMP	STIME	ATEMP	ATIME
1	48.72	48.93	49.04	48.37
2	49.08	48.88	49.14	49.27
3	49.21	49.2	48.83	49.37
Delta	0.48	0.31	0.31	0.99
Rank	2	3	4	1

Table 10: shows response table for means.

Level	STEMP	STIME	ATEMP	ATIME
1	273.4	280.4	284	262.5
2	285.3	278.7	286.6	290.9
3	288.8	288.5	276.9	294.1
Delta	15.4	9.8	9.8	31.6
Rank	2	3	4	1



From the above graph there is substantial change in ultimate tensile strength of material with increase in Solutionizing temperature and the highest of solutionizing time found to be one and half hour.It is also observed that ultimate tensile strength is highest at 200ºC Ageing temperature at 18 hrs of ageing time.

IX. CONCLUSIONS

The following are the conclusions made as follows as:

- Taguchi design can be very efficiently used in the optimization of welding parameter to find the optimum Hardness and Tensile strength of dissimilar welded joints of aluminium alloy 6061and AA 5154 material.
- The influence of post welded heat treatment is observed to be the best method to improve the mechanical properties of aluminium alloys.
- It is observed that there is substantial improvement in Ultimate tensile strength of material is increased by approximately 20 % and Hardness is increased 25 % approximately.
- Further the optimised results found to be best for solutionizing temperature as 530º C and Peak Ageing temperature as 200º C for 18 Hrs of Ageing time.

- With the use shielding gas helium and 4643 filler material both substantially improved surface quality of the welded joint.
- The result achieved shows that by means of an appropriate selection of age hardening parameters, it is possible to achieve a better understanding of joining of TIG welded AA 6061 and AA 5154 aluminium alloy

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