To Study the Micro-Structural of Aluminum Alloy AA-6061 Welded Using TIG Welding Process at Different Welding Current

Ishteyaque Ahmad[1], Somvir Arya[2]

[1]Research Scholar, Mechanical Engineering Department, Indus Institute of Engineering & Technology, Kinana (Jind) Haryana India

[2]Assistant Professor & Head, Mechanical Engineering Department, Indus Institute of Engineering & Technology, Kinana (Jind) Haryana India

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Abstract: Tungsten Inert Gas welding is the process in which heat is produced from an arc between the non-consumable tungsten electrode and the work piece. This paper deals with the study of Micro-structural and mechanical properties of the welded joints of the aluminum alloy AA-6061 welded by Tungsten Inert Gas(TIG) welding by using welding current as varying parameter. The filler wire used during the experiment of the grade as AA-4047 which has the more content of the silicon (11.0%-13.0%). Due to high content of silicon in the wire it will improve the fluidity during the welding operation. By this experiment we will examine the optimal value of the welding current. The welded specimens are to be investigated by using the optical microscopy, Vickers micro-hardness test and surface roughness testing. The optical microscopy test was used to characterize the micro-structure of the base metal and of the welded zone and the micro-hardness test was conducted to find the hardness of the welding zone and surface roughness test was conducted to check the roughness of the welded surface.

Keywords: Aluminum, Alloy, AA-6061, Welding, TIG Welding

1. Introduction:

Welding is a process of joining two similar or dissimilar metals by fusion with or without the applications of pressure and with or without the use of filler metal. Aluminum posses high thermal expansion co-efficient, high heat transfer specific heat and high electrical transfer due to which fusion welding process are not suitable for aluminum alloys. Because due to high co-efficient of thermal expansion there will take place the deformation during fusion welding. And because of high heat transfer in aluminum the laser welding technique cannot be used and due to high electrical conductivity we cannot be prefer the resistance welding also. It is important to understand the differences between the various aluminum alloys available and also the performances and welding characteristics.

It is often said that the arc welding of aluminum is not difficult but it is just different to understand the differences between the welding of different aluminum alloys. We certainly have to study about the family of the aluminum alloy. TIG welding is mostly preferred for the aluminum alloy because it starts to spread out from weld pool during the welding operation when compared to other process.

Usually the mechanical properties and the microstructure of the aluminum alloys will be change after the welding because of the melting of the base material during the welding process. Types of joints and the shielding gases also affect the mechanical properties of joints.

1.1 Tungsten Inert Gas welding / TIG:

TIG (Tungsten Inert Gas) welding is also known as GTA (Gas Tungsten Arc) in USA and WIG (Wolfram Inert Gas) in Germany is a welding process in which a non-consumable tungsten electrode is used to make a weld.

1.2 Principle of TIG welding Process:

During the TIG welding heat is generated through the arc of electricity which jumps from the tungsten electrode to the metal surface which we have to weld. TIG(as shown in the fig. 1) welding set utilizes suitable power source, a welding torch having connections of cable for current, tubing for shielding gas supply, and tubing for water for cooling the torch. TIG welding process uses a non-consumable tungsten electrode to heat and melt the work piece. The electrode is mounted in a special electrode holder. This electrode holder is also designed to furnish a flow of inert gas around the electrode and around the arc. Welding operation is done by striking the arc between the work piece and tungsten electrode in an atmosphere of inert gas. The arc is struck either by touching the electrode with a scrap metal tungsten piece or using a high frequency unit. After striking the arc, it is allowed to impinge on the job and a molten weld pool is created. The welding is started by moving the torch along the joint and is stopped at the other end by increasing the arc length. The shield gas is allowed to impinge on the solidifying weld pool for a few seconds even after the arc is extinguished. This will avoid atmospheric contamination of the weld metal. The welding torch and filler metal are generally kept inclined at angles of 70 degree – 80 degree and 10-20 degree respectively with the flat work piece. Filler metal, if require should be added by dipping the filler rode in the weld pool. When doing so, the tungsten electrode should be taken a little away from weld pool. However the heated end of filler rode as well as the electrode should be within the inert gas shield. Both D.C. and A.C. power source can be used.

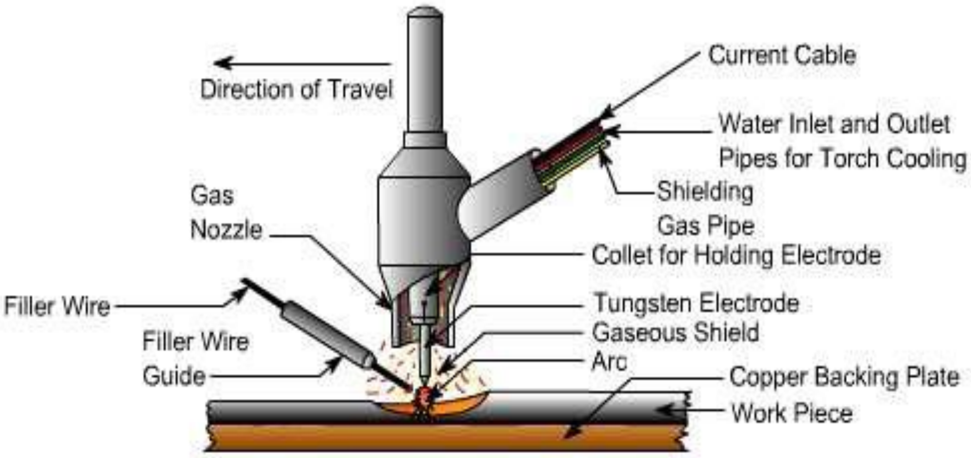

Figure 1: Diagram of principle of TIG welding

1.3 Parameters of the TIG Welding:

Parameters which are mainly used during the TIG welding and affected welding properties are given below:

1) Power Source.
2) TIG Torch.
3) Tungsten Electrodes.
4) Welding Speed
5) Shielding gases

1) Power Source: In the TIG welding both the AC and DC current are used. For the welding of Stainless Steel, Mild Steel, Copper, Titanium, Nickel, Alloy etc. use the DC source. And the AC sources are used for the welding of Aluminum and its alloy and also for magnesium.

2) TIG Torch: The main function of the TIG torch (as shown in fig.2) is to carry the welding current and shielding gas to the weld. The TIG may be the air cooled or water cooled of different size.

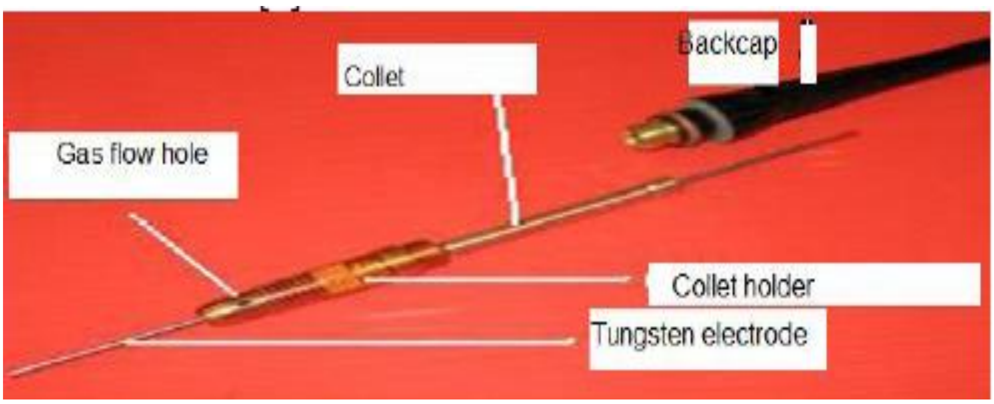

Figure 2: Main components of TIG torch

These are designed according to the area of welding and the required welding current. Water-cooled torches are mostly used for the welding with large current intensity and for AC welding. Water-cooled TIG torch is smaller than the air – cooled in the case of same maximum current intensity.

3) Tungsten Electrodes: During the TIG welding the electrodes are made up of pure tungsten or tungsten oxide. Pure tungsten is very heat resistance material with a fusion point of approximately 3380 °C. Pure tungsten having green colour and especially used for AC welding of aluminum and aluminum alloy. Tungsten with 2% Thorium having red color and used for non-alloyed and low-alloyed steels as stainless steel. Tungsten having 1% Lanthanum have black colour and it is suitable for all TIG welding material.

4) Welding Speed: Welding speed is an important parameter for TIG welding. Welding speed helps in the controlling of the weld bead size and penetration of bead. When the welding speed is °increased power per unit length of weld is decrease therefore less weld reinforcement results and penetration of welding decreases. It is dependent of supply of current. The excessive high welding speed decrease wetting action and uneven weld bead shapes. While slower welding speed reduce the tendency of porosity.

5) Shielding Gases: During the TIG welding the shielding gases are used to prevent the molten metal from the harmful effect of atmospheric air. Due to small amount of oxygen in will oxidise the alloying elements and create the slag inclusions. Due to nitrogen there is the brittleness in the welding zone. The shielding gases influence the welding properties and have the great importance in the penetration and in the weld bead geometry. For the TIG welding process different types of shielding gases are used :

a) Argon (Ar):
b) Helium (He):
c) Carbon dioxide (CO_2):
d) Hydrogen (H_2):
e) Oxygen (O_2):
f) Nitrogen (N_2):

1.4 Selection of material:

There are a lot of aluminum series such as 2xxx, 3xxx, 4xxx, 5xxx, 6xxx, and 7xxx used for different purposes according to their requirement. Every series have its different applications according to its material composition. For example 2000's series is mainly used for air craft alloy, 3000's series is good for workability and weld ability, 6000's are good for corrosion resistance, 7000's series have more strength and used for air frame structure. From all of these series we have selected the material as AA-6061-T651 from 6000's series due to its moderate strength and good corrosion resistance.

2. Literature:

Balakrishna [1] investigated the effect of modified filler rod of grade AA-5356 on the corrosion behaviour of the aluminum alloy AA-6061 with the help of Gas Tungsten Arc (GTA) welding. The gas tungsten arc welding technique take place with continuous current (CC) and pulsed current with the filler wire used as AA-5356. When the pulsed current GTA welding was adopted as compared to continuous current then the pitting corrosion resistance of aluminum alloy AA-6061 was less. Pitting corrosion resistance of aluminum alloy AA-6061 was relatively less when filler materials contained grain refiners such as scandium, Zr or Tibor. Highest pitting corrosion in aluminum alloy AA-6061 was found when filler wire AA-5356 containing 0.5% Sc was used with pulsed arc GTA welding.

Senthil [2] have made a research on the study of the pitting corrosion behavior of aluminum alloy AA-6061 with the effect of pulsed current TIG welding parameters. The pulsed current parameters have found to improve the mechanical properties of the weld compared to those of continuous current weld of this alloy due to grain refinement occurring in the fusion zone. With the increase in the value of peak current the pitting corrosion resistance will also be increased. The effect occurs with the increment in frequency. And when there is the increment in the base current the pitting corrosion resistance will be decrease.

Michinori [3] have investigated the mechanical properties of aluminum based dissimilar alloy joints by Power Beams Arc and friction stir welding processes. The metals used in the experiment were A1050-H24, A2017-T3, A5083-O, A6061-T6, and A7075-T651. The specimen used of the different aluminum alloy with the thickness 3 mm. Aluminum alloy A5083/A6061 welded by friction stir welding have the highest hardness value in stir zone through the weld metal as compared to the other fusion welding processes. Friction stir welding providing the highest tensile strength to the aluminum alloy A2017/A7075 age-hardening aluminum joint. As in the Power Beam welding such as EBW and LBW process fusion and solidification zones are very narrow. So the heat input is in low level compared to MIG and TIG welding process.

Venugopal [4] Investigated the mechanical properties of aluminum alloy AA-7075 -T6 with the impact of M2-Hss tool pin profile in friction stir welding. Three different tools (Taper Threaded, Cylindrical and square) were used to construct the joints in the particular rotational speed. Tensile, impact and micro hardness of mechanical properties of the joint to be find out and formation of FSP zone has been analyzed microscopically. Grain refinement has been achieved due to friction stir welding and plastic flow. The threaded cylindrical profile produces highly strength in welds at 800 rpm.

Lakshman [5] have investigated the effect of welding parameters such as welding current, gas flow rate and welding speed on the tensile strength of the aluminum alloy AA-5083 with the use of TIG welding. The specimen size used for the experiment is 100 mm x 15 mm x 5 mm of aluminum alloy AA-5083. Maximum strength of 129 MPa is achieved when the welding current is used of 240 amps and the gas flow rate used as 7 Lt/min. The welding speed for high tensile strength kept as 98 mm/min. The tensile strength of weld joint of aluminum alloy AA-5083 increase with the increase in welding speed up to an optimum value after that value the tensile strength decreases. So the optimum range parameter for maximum tensile strength were found as welding current 240 ampere, welding speed 98 mm/min and gas flow rate 7 Lt/min.

Krzysztof [6] have made a research on the comparison of the mechanical properties of the aluminum alloy AA-7020 with the aluminum alloy such as AA-5083 and alloy AA-5059 by using the friction stir welding. The research was being taken place at temperature of +20°C The aluminum alloy AA-7020 have higher strength properties than the aluminum alloy AA-5059 and AA-5083. The yield stress of alloy AA-7020 is higher than the aluminum alloy A-5083. Despite the strength properties also the plastic properties are best for alloy AA-7020 welded joints.

Krzysztof [7] have investigated the comparison of the mechanical properties of the aluminum alloy AA-7020 with the aluminum alloy AA-5083 and alloy AA-5059 by using the MIG welding. The flat samples are cut perpendicular to the direction of rolling being used. The research was conducted at the temperature of +20°C. The joints welded by MIG welding of the aluminum alloy AA-7020 have the higher yield stress compared to the aluminum alloy AA-5059 and alloy AA-5083. Plastic properties of the aluminum alloy AA-7020 are the lowest. The welded joints of aluminum alloy AA-7020 have the higher strength as compared to alloy AA-5083 and AA-5059.

Susil [8] conducted an experimental investigation to study the mechanical properties of aluminum alloy AA-6106-T6 joined by friction stir welding and TIG welding. The specimen size was selected as 160 mm x 30 mm x 3 mm prepared with milling machine. The tensile strength of the alloy AA-6106-T6 welded with friction stir welding is more than that of the TIG welding. The welded specimens have lower mechanical properties as compared to the base material. The hardness of friction stir welding is more than that of TIG welding.

Sathish [9] have investigated the welding of dissimilar metals, carbon steel, and stainless steel with the use of GTAW (Gas Tungsten Arc Welding) process. The specimen selected size was taken as 7.11 mm thickness and with length 150 mm. And the used variable for the welding purpose were gas flow rate, heat input and bevel angle. With the low value of heat input lower is the tensile strength and with the too high value of heat input also the lower tensile strength. So the intermediate values of heat input range 1500 to 1600 J/min for higher tensile strength. The optimum range take place at the current value as 110 to 115 ampere, gas flow rate as 12.5 Lt/min and the bevel angle of 45 degrees.

Devakumar [10] Tungsten Inert Gas (TIG) is an electric arc welding process, which produces an arc between a non-consumable tungsten electrode and the work to be welded. Stainless steel is most widely used in the industries due to its non-corrosion behavior. In this paper an attempt was made to review and consolidate the important research works done on GTAW of stainless steel in the past, by various researchers. Its observed that most of the work is done on austenitic stainless steel, which is the most widely used type of the stainless steel in the world. Major areas of research have been in characterization of weld, dissimilar metals welding, parameter optimization, process modeling, failure analysis and automation of TIG welding process. This paper provides a brief idea about the research work done in the past on TIG welding of stainless steel by various researchers, by highlighting the important conclusions and results.

Jeyaprakash [11] investigated the influence of the power source, types of currents, gas flow rate, electrodes, filler wires, TIG machine settings, and shielding gases which are most important in determine arc stability, arc penetration and defect free welds. For this a thorough literature survey is carried out on various aspects of the proposed topic, in various peer–reviewed journals, patents, books, and other sources. In this paper suitable range of the current, the thickness of the base metal, the diameter of the electrode filler wire and the gas flow rate are to be identified for high quality TIG welding process.

2.1 Research Gap:

After a comprehensive study of the different literatures, a number of gaps have been observed in the research of Tungsten inert gas welding of the material as aluminum alloy AA-6061-T651.

1) Most of the researches have studied the Tungsten inert gas welding on type of different aluminum alloy like as AA-6351, AA-5083, AA-7075, AA-5052, AA-5754, etc. But now there will be the work mentioned in the literature regarding TIG welding of aluminum alloy material AA-6061 at different welding current.

2) There we will have to investigate the weld strength hardness of welding joint and change in the microstructures and surface roughness of the aluminum alloy AA-6061-T651 at different value of welding current having gas flow rate as constant in each case. Then find out the optimum value of welding current for better properties.

3. Experimental Procedure:

Aluminum alloy AA-6061 is selected for the process according to the requirement. Then the alloy will be cut with the help of cutter in the small pieces having the dimensions as 200 mm x 150 mm x 6 mm. Grinding is done on the surface of the piece for the smoothness of the surface. After that the plates are polished with emery paper to remove any kind of external material.

Now the pieces were placed on the surface plate to make them joint with the help of welding. Weights are placed on both of the plates to prevent them from bending. The welding was done manually at the different value of current having the constant gas flow rate.

First of all about the TIG welding set up :-

Manually operated TIG welding machine working on alternating current as shown in figure 3:

Gas used for the welding operation as Argon gas.

Gas pressure remains inside the Argon gas cylinder as 27 lb/m^2.

Temperature written inside the gas flow rate tube was 20 °C.

Tungsten electrode used for the welding having diameter as 2.4 mm.

Filler wire used of grade AA-4047 having the diameter as 1.6 mm.

Gas nozzle diameter for gas flow as 12.5 mm.

TIG Welding at the current value as 140 ampere:-.

Welding current during experiment = 140 ampere

Gas flow rate kept as = 10 liter/minute

Figure 3: AC welding machine showing current as 140 Ampere

In this AC welding machine the current is shown as 140 ampere on the left and on the right side there is shown as zero which defines the voltage. The value of voltage changes takes place on the place of zero during the welding process. There is shown a round regulator with red top which is used to adjust the welding current before welding.

Figure 4: Argon Gas pressure gauge and gas flow regulator

The glass tube (shown in figure 4) is used to measure the pressure of gas flow rate of the used Argon gas. The gas pressure shown in the glass tube of Argon gas cylinder was as 27 lb/m^2. The temperature written inside the glass flow rate tube was 20 °C. The green colour pressure gauge was also used on the cylinder.

At the value of welding current as 140 ampere the welding joint between the two pieces take place. The gas flow rate was kept as10 liter/minute. During the TIG welding using alternating current as 140 ampere the value of voltage varies from 12.7 volts to 13.4 volts. During the welding the value of fixed current may also varies two or three points for example during the welding load the current may reach the value of approximately as 142 ampere. The welding was take place on the horizontal flat plate from the left end to the right end with a constant manually speed. The time taken during the welding was approximately 67 second. The welding type was the single pass welding as shown in figure 9 on the one side.

Figure 5: Welding Plate after TIG Welding at the value of current as 140 ampere

4. Result & Discussion:

4.1 Testing of the welded specimen:

After the welding the welded specimen are passed through the microstructure testing and micro-hardness testing of the base material and of the welded portion. The surface roughness of the specimens was investigated at Jind Institute of Engineering &Teechnology Jind (India) by using Mitutoyo SJ-201 surface roughness tester. Surface roughness of the specimens was measured along the length of the weld bead.

4.2 Microstructure Testing:

The specimens having the size as 200 mm x150 mm x 6 mm are welded at different welding current. The specimens have flat size as 50 mm x 10 mm x 6 mm cut from the welded piece. After cutting the flat size pieces were grinded. After that the polishing were done on the surfaces of the specimens with the help of grit size rough emery papers. For the polishing purpose different types of grades were used of the grit emery papers. The grit size papers used for polishing have the grades as 180, 220, 320, 400, 600, 800, 1000 and 1200. After the polishing the specimens were passed through the etching process.

The etching process was done with the help of etching liquid solution. The etching process was the final process after polishing. During the etching process Brasso-Liquid mixture were used having HF (Hydro-fluidic acid) as 0.5 %. After etching process the microstructure of the specimens was captured on an optical Microscope at 200X magnification. Versamet Unitron 5463 inverted optical microscope (as shown in the fig. 15) with the zooming range of 50-400 μm has been used to study the microstructure of the base material and of the welded material. The standard used for the microstructure testing was ASM 9, 2004.

Figure 6: Optical microscope

4.3 Surface Roughness:

Surface roughness indicates the state of a machined surface. When representing the surface of a component surface roughness can be examined by or rubbed with finger tip. When a surface's level of shininess is clearly quantified it is called surface roughness, which plays an important role in defining the character of a surface. The surface irregularities of a material may be intentionally created by machining. The shape and size of the irregularities on the machined surface have major impact in the quality and performance of that surface, and on the performance of the end product.

Two types of instruments are used to measure surface roughness:

1) Contact type instruments.
2) Non-contact type instruments.

Contact type instruments:

In this type of instrument the tip of the stylus directly touches the surface of the sample shown in figure 7. When the stylus traces across the sample it rises and falls together with the roughness on the surface of sample. The stylus moves closely with the sample surface so the data is highly reliable.

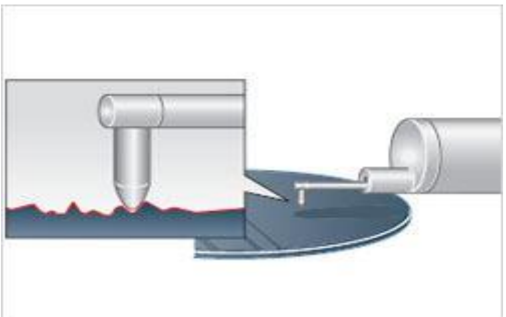

Figure 7: Contact type surface roughness tester

Non-contact type instruments:

A light emitted from the instrument is reflected and read to measure without touching the sample.

4.4 Surface Roughness Testing:

The surface roughness was investigated at Jind Institute of Engineering & Technology, Jind (India). For the testing contact type Mitutoyo SJ-201 surface roughness tester (as shown in figure 8) was used. The stylus acted on the top of the equipment was traced over the welded part of the sample. The stylus goes up and down across the welded part. During this movement the digital meter shows the zero reading on any place then we press the start button. After sensing the surface by the stylus the reading are shown on the meter. After that the stylus is again move over the welded surface for the further reading.

Figure 1 : Surface roughness tester

4.5 Microstructure of the welded part at the welding current as 150 ampere:

After the perfect preparation (by polishing and etching) of the specimen the microstructure of the welded part welding at 150 ampere was taken out by the optical microscope. The method used for the testing was ASM 9, 2004. During the welding we have to use the filler wire of grade AA-4047 which has more amount of silicon in it. Due to this the microstructure as shown in the figure 21 consists of inter-dendritic network of the aluminum silicon eutectic in matrix of aluminum solid solution. The microstructure of the specimen was shown with the magnification as 200X and with a zooming range of 50-400 µm.

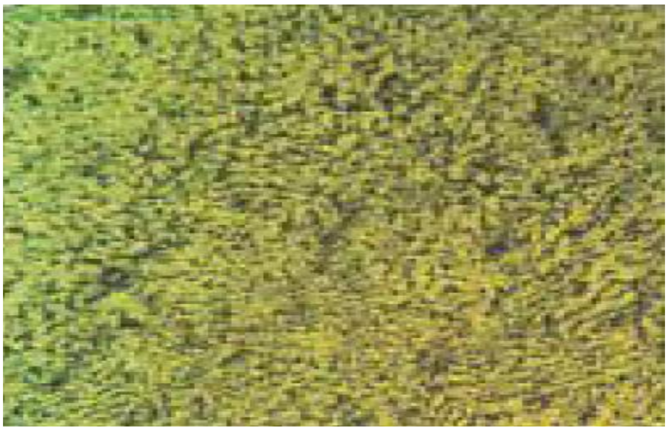

Figure 9: Microstructure of the welded part at the welding current as 150 ampere

4.6 Micro-hardness of the welded part at the welding current as 150 ampere:

To check the micro-hardness of the welded specimen welding at 150 ampere, place the specimen on the Mitutoyo MGKH1 Vickers hardness tester. We will find out the two different values of the micro-hardness at same distance on the both sides of the centre point. The micro-hardness value for the welding current 150 ampere was 68 and 70. The method used for the testing was IS1501(Part1):0213. The hardness value on the right 2.5 mm away from the centre towards the right was 68HV1 (where 68 define the hardness value and 1 for weight in kilogram). And value of hardness on the left side as 2.5 mm away from the centre was 70HV1 (where 70 define the micro-hardness value and 1 define the weight in kilogram).

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