# Wear Behavior of Mg Alloy Reinforced With Aluminum Oxide and Silicon Carbide Particulates

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*Abstract*— Light weight metals like magnesium and its alloys are in more use these days in automotive & aerospace industries. Magnesium based hybrid structures which are combinations of magnesium and another material like Aluminium can offer optimal technical performance due to the favorable strength-weight ratio. Materials with improved tribological properties have become the pre-requisite of advanced engineering design. Metal matrix composites (MMCs) exhibit a unified combination of good tribological properties and high toughness of the interior bulk metal when compared with monolithic materials. Stir processing, a microstructure modification technique, has emerged as one of the processes used for fabrication of MMCs. Commercial cast or wrought type Mg–Al–Zn AZ-series alloys, such as AZ91 9 wt.% Al and 1 wt.% Zn, have been widely used in automobiles or electronic appliances. Tribological performance of the fabricated composite will be investigated using pin-on-disc wear & friction monitor. In this paper, a novel approach of making hybrid preforms with two types of reinforcements, i.e., lowcost and different sized particles, for magnesium-based composites is planned. This paper investigates the wear behavior of magnesium alloy (similar to commercially available AZ91) based metal–matrix composites (MMCs) reinforced with Silicon Carbide (SiC) & Aluminium oxide ($Al_2O_3$) particulates during dry/wet sliding.

***Key words***: Magnesium, Silicon Carbide (SiC), Aluminum oxide ($Al_2O_3$), Stir Casting, Pin-on-Disc Tribometer, Micrographs

## I. INTRODUCTION

Magnesium is a very promising light metal for the universal use in Aerospace, vehicles & so on. Traditional materials like steel and cast iron or even also Al can be replaced with it in automotive parts. Mg alloys have by 33% lower density in comparison to Al and by 77% compared to steel. On the other hand, the wear resistance and stiffness of Mg is not sufficient for many applications. In order to improve the technical performance of magnesium based machine part the material has to be reinforced while requirement of low weight can be also fulfilled. The application of lightweight construction of magnesium based hybrid material parts has been extended in the last few years. Since recent casting technologies made possible to include other materials directly into mould parts. Magnesium– aluminum-silicon (Mg–AlSi hybrid) are used more and more. Promising application in automotive industry [2] is the Mg-based hybrid engine block. Despite the potential of Mg MMCs, their study has been relatively limited when compared to abundance of Al MMC investigations over the last two decades. Research on the tribological properties of these materials is even scarcer. Among the earliest was a study by Li et al. [5], which examined wear behavior of $SiC_p$-reinforced magnesium & Mg-9Al-1Zn composite sliding tests. They noted that presence $SiC_p$ does not appear to be beneficial in reducing wear rates. The hybrid material is advantageous due to its low weight combined with high strength, good wear characteristics and heat resistance. Structural parts exposed to heavy loads are produced of wear or heat resistant, high strength materials like AlSi. These embedded parts improve the relative poor mechanical strength of magnesium alloy while the high volumetric proportion of magnesium ensures low weight for the whole structure. The advantages of composites are only realized if a reasonable cost performance ratio is achievable on production of the component. In this respect it is important for economic and ecological reasons to recycle crap components, production waste, etc.

### A. Composites

Composite materials (also called composition materials or shortened to composites) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.

### B. Hybrid Materials

Composites consisting of two constituents at the nanometer or molecular level. Commonly one of these compounds is inorganic and the other one organic in nature. Thus, they differ from traditional composites where the constituents are at the macroscopic (micrometer to millimeter) level. Mixing at the microscopic scale leads to a more homogeneous material that either shows characteristics in between the two original phases or even new properties.

### C. Reinforcement

A material in which a continuous metallic phase (the matrix) is combined with another phase (the reinforcement) to strengthen the metal and increase high-temperature stability. The reinforcement is typically a ceramic in the form of particulates, platelets, whiskers, or fibers. The metals are typically alloys of aluminum, magnesium, or titanium.

In this work silicon carbide (Sic) & Aluminium oxide ($Al_2O_3$) particulates are used as the reinforcing metal in Mg-9Al-1Zn composites.

### D. Tribology

Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. Tribology is a branch of mechanical engineering and materials science.

### E. Friction

Force resisting the motion of two solid surface, fluid layers, and material elements sliding against each other. Types of friction are:

(1) Dry friction.

(2) Fluid friction.
(3) Sliding friction.

### F. Wear

Wear is erosion or sideway displacement of material from its "derivative" and original position on a solid surface performed by action of another surface.

## II. MATERIALS & PROCESSING

### A. Magnesium Alloy

Magnesium alloys are mixtures of magnesium with other metals (called an alloy), often Aluminium, zinc, manganese, silicon, copper, rare earth sand zirconium. Magnesium is the lightest structural metal. Magnesium alloys have a hexagonal structure, which affects the fundamental properties of these alloys. Plastic deformation of the hexagonal lattice is more complicated than in cubic latticed metals like Aluminium, copper and steel. Therefore magnesium alloys are typically used as cast alloys, but research of wrought alloys has been more extensive since 2003. Cast magnesium alloys are used for many components of modern cars, and magnesium block engines have been used in some high-performance vehicles; die-cast magnesium is also used for camera bodies and components in lenses, alloys AZ91 are most used for die castings. However the prepared material is similar to the commercially available magnesium alloy AZ91.

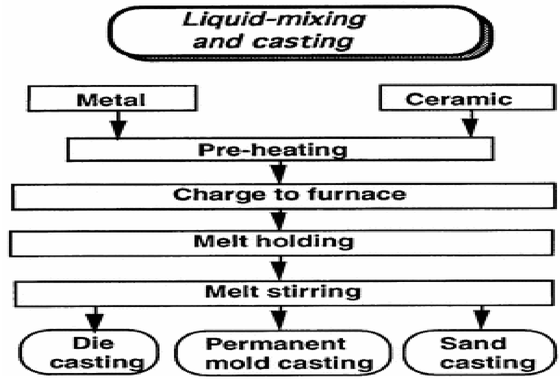
### B. Process for fabricating metal matrix composite

A key challenge in the processing of composites is to homogeneously distribute the reinforcement phases in the matrix to achieve a defect-free microstructure. Based on the shape, the reinforcing phases in the composite can be either particles or fibers. The relatively low material cost and suitability for automatic processing has made the particulate-reinforced composite preferable to the fiber-reinforced composite for automotive applications. Due to the similar melting temperatures of magnesium and aluminum alloys, the processing of a magnesium matrix composite is very similar to that of aluminum matrix composites. For example, the reinforcing phases (powders/fibers/whiskers) in magnesium matrix composites are incorporated into a magnesium alloy mostly by conventional methods such as stir casting, squeeze casting, and powder metallurgy. In this work stir casting has been used.

### C. Stir Casting

In a stir casting process, the reinforcing phases SiC & $Al_2O_3$ (particulate form), 9wt% Al (beads/stripes form) & 1wt%Zn (bricks form) are distributed into molten magnesium by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S.Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. Magnesium composites Mg-9Al-1Zn reinforced with Silicon Carbide (SiC) & Aluminium Oxide ($Al_2O_3$) particulates have been produced using this method.

### D. Typical stir casting process




A homogeneous distribution of secondary particles in the composite matrix is critical for achieving a high strengthening effect because an uneven distribution can lead to premature failures in both reinforcement-free and reinforcement-rich areas. The reinforcement-free areas tend to be weaker than the other areas. Under an applied stress, slip of dislocations and initiation of micro-cracks can occur in these areas relatively easily, eventually resulting in failure of the materials. In the areas of significant segregation or agglomeration of normally highly brittle hard particles, weak bonds are formed in the material which can lead to reduced mechanical properties. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification. Solidification of any melt stirred composites will result in an uneven distribution of particles on a micro scale. This is caused by the 'pushing' phenomenon where the growing matrix dendrite expels the particles as it grows. The result is a necklace distribution of particles. The severity of this is thus dependent on grain size and can be minimized by using fine grained alloys or rapid cooling rate processed. The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added. An interesting recent development in stir casting is a two-step mixing process. In this process, the matrix material is heated to above its liquids and solidus points and kept in a semisolid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. The resulting microstructure has been found to be more uniform than that processed with conventional stirring. The effectiveness of this two-step processing method is mainly attributed to its ability to break the gas layer around the particle surface. Particles usually have a thin layer of gas absorbed on their surface, which impedes wetting between the particles and molten metal's. Compared with conventional stirring, the mixing of the particles in the semi-solid state can more effectively break the gas layer because the high melt viscosity produces a more abrasive action on the particle surface. Hence, the breaking of the gas layer improvers the effectiveness of the subsequent mixing in a fully liquid state. Another concern with the stir casting process is the entrapment of gases and unwanted inclusions. Magnesium alloy is sensitive to oxidation. Once gases and inclusions are entrapped, the increased viscosity of the vigorously stirred melt prevents easy removal of these detriments. Thus, the stirring process needs to be more judiciously controlled for a magnesium alloy than for an aluminum alloy in order to prevent the entrapment of gases and inclusions. In principle, stir casting allows for the use of conventional metal processing methods with the addition of an appropriate stirring system such as mechanical stirring; ultrasonic or electromagnetic stirring; or centrifugal force stirring.

Fig: Induction Furnace Fig: Mould used


Fig: Reinforcements


Fig: Prepared reinforced Mg-9Al-1Zn

The major merit of stir casting is its applicability to large quantity production. Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical (Compared to other methods, stir casting costs as little as one third to one tenth for mass production). For that reason, stir casting is currently the most popular commercial method of producing aluminum based composites. However, no commercial use of stir casting has been reported on magnesium matrix composites.

## III. RESULTS & DISCUSSION

Chemical testing was done on the prepared reinforced samples using ASTM E35-1980 & the following results were obtained.

**CHEMICAL ANALYSIS (%)**

| S.No | Material Identification | Al | Mn | Fe | Cu | Zn | Si | Mg |
|---|---|---|---|---|---|---|---|---|
| 1 | MAGNESIUM ALLOY , AZ91 1ST RUN AL2O3 1% SIC 3% | 9.10 | 0.096 | 0.003 | 0.003 | 0.88 | 0.012 | REM |
| 2 | MAGNESIUM ALLOY , AZ91 2ND RUN AL2O3, 3% SIC 1% | 8.90 | 0.024 | 0.002 | 0.001 | 0.66 | 0.018 | REM |

### *A. Wear Testing*

Dry & wet sliding wear tests were conducted using pin-on-disc tester. Pin specimens of diameter 8mm & length 22-24mm were machined.

All experiments were conducted in normal atmospheric conditions with applied normal loads of 30N using dead weights, while five sliding speeds (1, 2, 3, 4 & 5 m/s) were selected. For each sliding condition tests, time of 5mins, speed of 500RPM, & a wear track diameter 60mm were selected.

### *B. Pin on disc tribometer (TR-20)*


Specifications of pin on disc Tribometer (TR-20):

- Makers: Ducom Ltd, Bangalore.
- Pin Size: 3 to 12 mm diagonal.
- Disc Size: 160 mm dia. X 8 mm thick.
- Wear Track Diameter (Mean): 10 mm to 140 mm.
- Sliding Speed Range: 0.26 m/sec. to 10 m/sec.
- Disc Rotation Speed: 100-2000 RPM.
- Normal Load: 200 N Maximum.
- Friction Force: 0-200 N, digital readout, recorder output.
- Wear Measurement Range: 4 mm, digital readout, and recorder output.
- Power: 230 V, 15A, 1 Phase, 50 Hz.

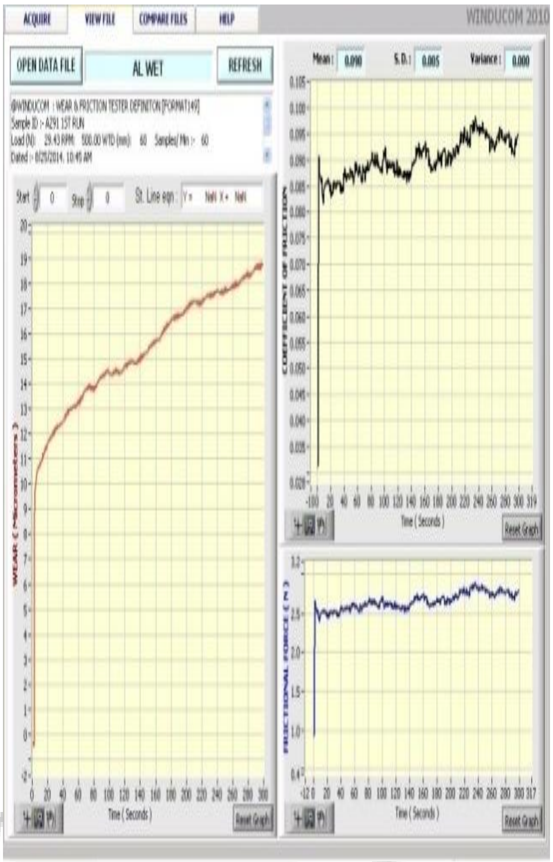


Fig: Wet test reports of Mg-9Al-1Zn composite reinforced with 1% $Al_2O_{3p}$ & $SiC_p$ 3% (File name: AL WET).

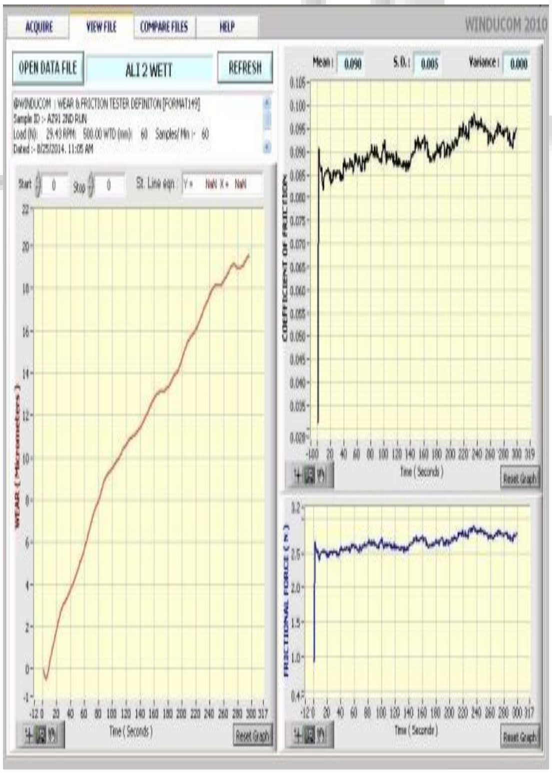


Fig: Wet test reports of Mg-9Al-1Zn composite reinforced with 3% $Al_2O_{3p}$ & $SiC_p$ 1% (File name: ALI 2 WETT).

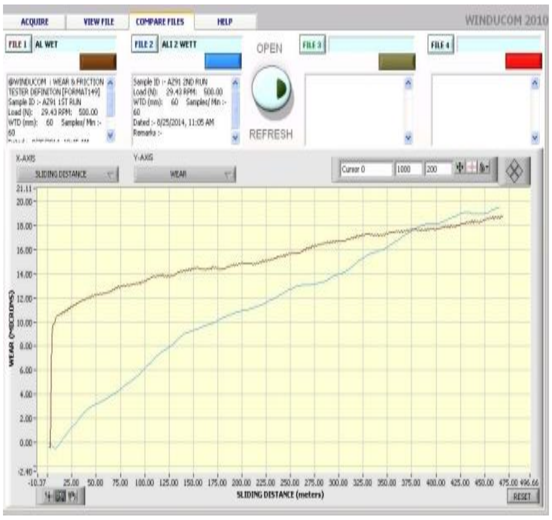


Fig: Wet sliding test comparison of the two reinforced metals.

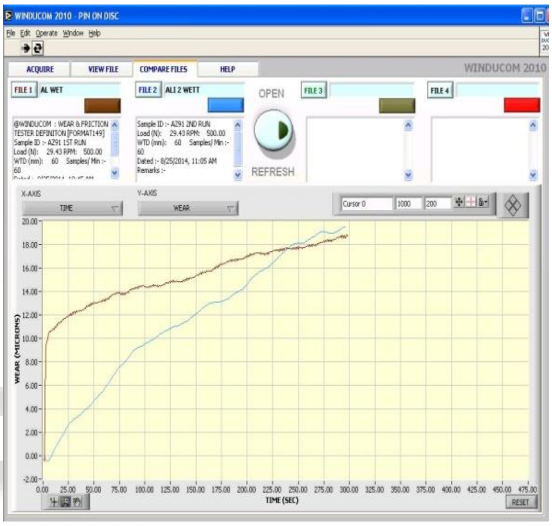


Fig: Wet wear behavior of the two reinforced metals with respect to time.

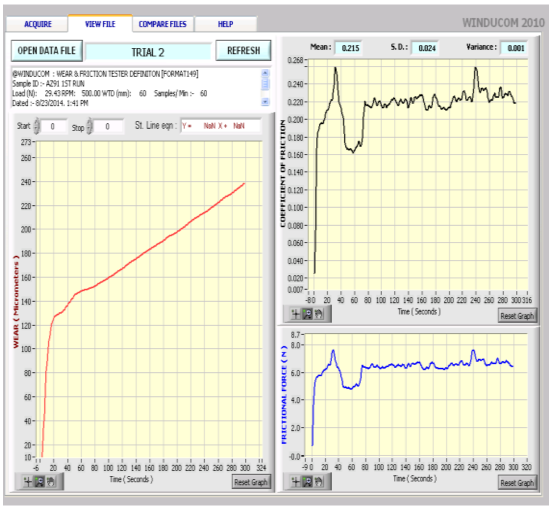


Fig: Dry test reports of Mg-9Al-1Zn composite reinforced with 1% $Al_2O_{3p}$ & $SiC_p$ 3% (File name: TRIAL 2).

Fig: Dry test reports of Mg-9Al-1Zn composite reinforced with 3% $Al_2O_{3p}$ & $SiC_p$ 1% (File name: trial test 1).

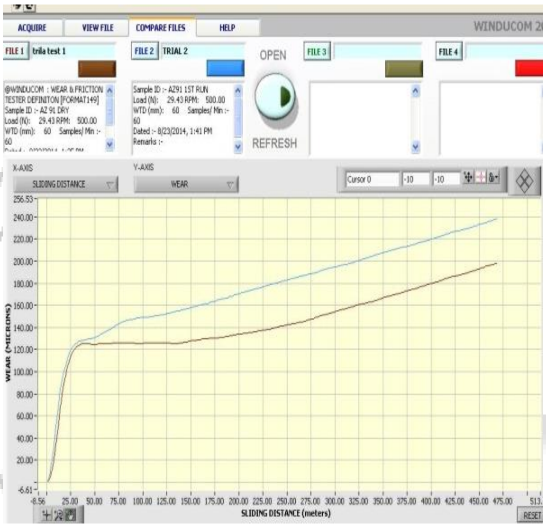


Fig: Dry sliding test comparison of the two reinforced metals.

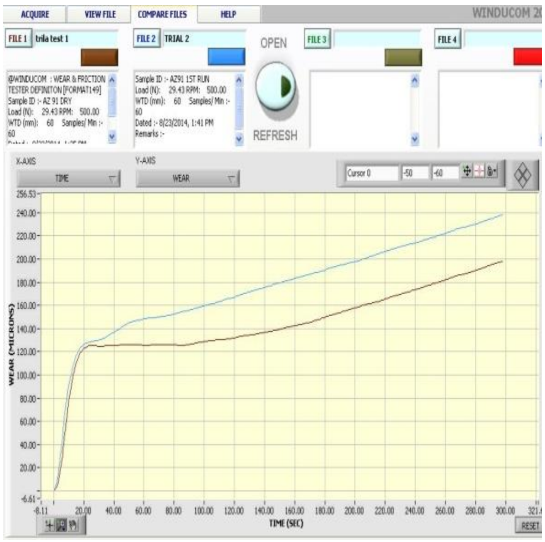


Fig: Dry wear behavior of the two reinforced metals with respect to time.

## IV. MICRO STRUCTURAL ANALYSIS OF REINFORCED MG-9AL-1ZN COMPOSITE

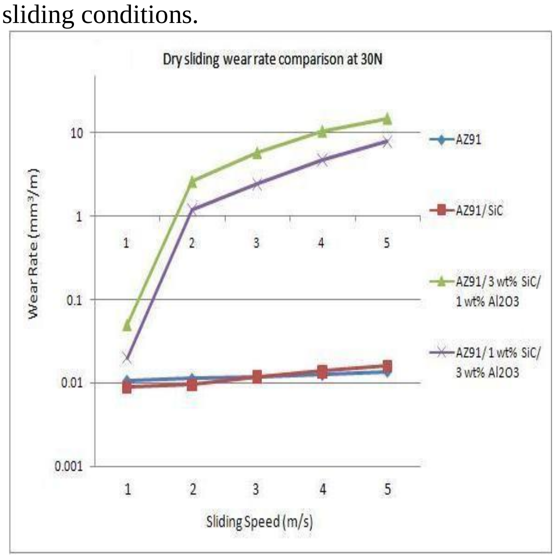
Analysis was carried out using Metascope Metallurgical Microscope with ASTM E 407 Standards using etchant solution containing - distilled water (50 ml), anhydrous ethyl alcohol (150 ml), glacial acetic acid (1 ml).

The grain size was determined and following photomicrographs were taken from the surface of Reinforced Mg-9Al-1Zn composite samples.

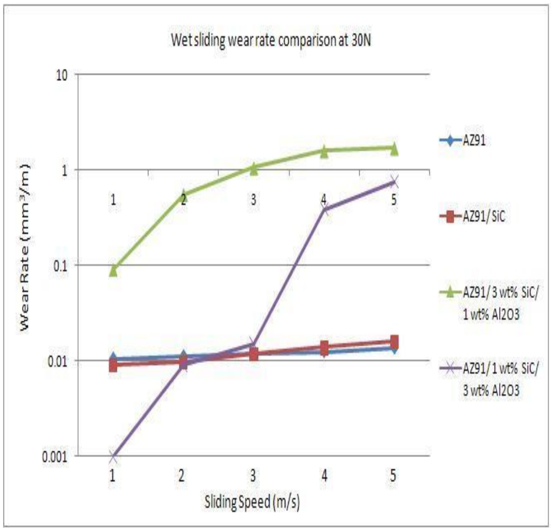

The microstructure consists of fine grains of magnesium in the matrix of Al.

## V. CONCLUSIONS

(1) Pin on disc wet & dry sliding wear tests of Mg-9Al-1Zn composite reinforced with $Al_2O_{3p}$ & $SiC_p$ pins against a steel counterface were carried out under loads of 30 N, & over a range of sliding speeds from 1-5 m/s. Wear rates observed in above all tests as compared to C.Y.H. Lim et al. [5] limits the use of the Mg alloy & its composite to milder sliding conditions.






(2) The used quantity of $Al_2O_{3p}$ & $SiC_p$ does not appear to be beneficial in reducing wear rates, hence some other quantity may be beneficial.

(3) A transition from mild to severe wear with increasing time was noted.

(4) Less accurate or less précised surfaces of the pin with un-uniformity may lead to random wear results.

(5) Wear track diameter may also lead to random wear results.

(6) Etchant used failed to identify or stain $SiC_p$ & $Al_2O_{3p}$ particles in the micrographs.

(7) One of the factors hindering wider adoption of Mg MMC's is the lack of comprehensive property data, thus making the qualification of these materials, especially under stringent aerospace industry standards difficult.

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