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HYBRID METAL MATRIX COMPOSITES AND FURTHER IMPROVEMENT IN THEIR MACHINABILITY- A REVIEW

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Abstract - In the present study, based on the literature review, the machining of hybrid Aluminium Metal Matrix composite (Al/SiC/Gr and Al/Si10Mg/Fly ash/Gr) is discussed. These hybrid MMCs can easily be machined by EDM and a good surface quality can be obtained by controlling the machining parameters. These Aluminium Metal Matrix composites with multiple reinforcements (hybrid MMCs) are finding increased applications because of improved mechanical and Tribological properties and hence are better substitutes for single reinforced composites. These materials are developed for bushes, bearings and cylinder liners in cast Aluminium engine blocks. The problems encountered during machining of hybrid MMCs and their amendments by the use of Electric Discharge Machining (EDM) are discussed.

Keyword - Metal Matrix Composites (MMCs), Ceramic whiskers, hybrid metal matrix composites (HMMCs), Electric Discharge Machining (EDM).

1. INTRODUCTION

A study of the history, status, and opportunities of Metal Matrix Composites is presented by evaluating the progression of available literature. The trends that existed and issues that still prevail are discussed and a prediction of the future for MMCs is presented. In many developed countries and in several developing countries there exists continued interest in MMCs. Researchers tried numerous combinations of matrices and reinforcements since work on MMCs began in the 1950s. This led to developments for aerospace, but resultant commercial applications were limited. The introduction of ceramic whiskers as reinforcement and the development of in-situ eutectics in the 1960s aided high temperature applications in aircraft engines.

In the late 1970s the automobile industries started to take MMCs seriously. In the last 20 years, MMCs evolved from laboratories to a class of materials with numerous applications and commercial markets. So as to enhance further the properties of MMCs more than two materials were added in the matrix such that to give birth to hybrid metal matrix composites. There have been tremendous strides in engineering materials since the Second World War, researchers from various manufacturing, metallurgy, aerospace and nuclear industries developed large number of super alloys. Since long back, metal matrix composites (MMCs) were introduced in the aerospace and aeronautics industries and later on MMCs reached to the automotive industry. However, MMCs are not widely used in these industries because of their poor performance in context of machinability. Such materials can only be machined, if we understand the reasons for their poor machinability and take effective measures to counter them.

Metal Matrix Composites (MMCs) are composed of a metal matrix and a reinforcement, or filler material, which confers excellent mechanical performance, and can be classified according to whether the reinforcement is continuous (monofilament or multifilament) or discontinuous (particle, whisker, short fiber or other). The principal matrix materials for MMCs are aluminum and its alloys. To a lesser extent, magnesium and

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titanium are also used, and for several specialized applications a copper, zinc or lead matrix may be employed. MMCs with discontinuous reinforcements are usually less expensive to produce than continuous fiber reinforced MMCs, although this benefit is normally offset by their inferior mechanical properties. Consequently, continuous fiber reinforced MMCs are generally accepted as offering the ultimate in terms of mechanical properties and commercial potential.

The UK's Advisory Council on Science & Technology in 1992 stated that MMCs can be viewed either as a replacement for existing materials, but with superior properties, or as a means of enabling radical changes in system or product design. Moreover, by utilizing near-net shape forming and selective reinforcement techniques MMCs can offer economically viable solutions for a wide variety of commercial applications.

In general, the major advantages of Aluminum Matrix Composites (AMCs) over monolithic materials e.g. iron, steel and other non-ferrous common metals are as follows:

- High specific strength
- High specific stiffness
- Higher elevated temperature strength
- Improved wear resistance
- Low density; high strength to weight ratio.
- Improved damping capabilities
- Tailor able thermal expansion coefficients
- Good corrosion resistance etc.

When at least three materials are present, it is called a **hybrid composite**. Al/SiC/Gr_p-MMC is one of the important hybrids composite among MMCs, which have SiC & Gr particles with Aluminum matrix. The SiC is harder than Tungsten carbide (WC) and Graphite particles provide high resistance to wear in the hybrid composite. Recently modern industry rapidly introducing different composites due to their unique properties such as low density and very light weight with high temperature strength, hardness and stiffness, high fatigue strength and wear resistance, in order to meet the challenge of liberalization and to maintain global competitiveness in the market. Side by side modern manufacturing engineers are also trying to introduce the better properties in the composite like, hybriding our usually available conventional composites such as Al/SiC-MMC, Al/Gr_p-MMC, Al/Al_2O_3-MMC etc.

The hybrid metal matrix composite like Al/(SiC_p + Gr_p)-MMC is one of the composites which have many unique properties over Al/SiC-MMC or Al/Gr_p-MMC. The wear resistance of Al/SiC/Gr_p composites increases with the increase of the graphite particle size. The improvement of wear resistance is mainly attributed to the enhancement of integrity of lubrication tribo-layer composed of a complex mixture of graphite as well as fractured SiC particles and some fine particles containing aluminum.

The aluminum alloy, reinforced with discontinuous ceramic reinforcements, is rapidly replacing conventional materials in various automotive, aerospace and automobile industries. Most of the parts obtained with Aluminum matrix composites through different manufacturing processes namely the process derived from the casting have different geometry and they usually need machining operations with the required dimensional and geometrical precision as well as good surface roughness (SR).

From literature review, it is understood that the researchers have been used various methods to machine composite materials but the production of complex shapes, groves, blind holes, dovetail slots and odd maple complex contours with high dimensional accuracy on Al/SiC/Gr_p-MMCs composite parts have also been difficult to obtain with traditional machining processes. From the published research work it is also clear that the MMCs are much more difficult to machine than any monolithic materials by conventional or non conventional machining techniques. Harder cutting tool materials than work piece materials are the basic requirement in conventional methods of machining in manufacturing, in which the work piece is converted into finished product or components of specific dimensional accuracy, size, and shape and by achieving required configuration with the interaction of the harder cutting tool material. But in case of machining of Al/SiC/Gr_p-MMCs, the reinforced SiC particles, are harder than Tungsten carbide (WC), which itself is a common cutting tool material in most of the cutting operations of hard materials. Al/SiC/Gr_p-MMCs are having very high value of hardness and stiffness, the selection of proper cutting material and method of machining for machining of such hard composites have really been very difficult.

Aluminum/Silicon/Graphite composite can be used in automobile components like piston, cylinder blocks for automobile engines that operate at a temperature up to 300 C. It is understood that it is difficult to make a quantitative comparison of the literature data, since the wear rate and friction coefficient strongly depend upon the testing method, testing environment, testing variables, composite manufacturing route and there enforcement volume fraction, size and hardness. It is due to excessive cutting tool wear, diffusion occurs, built-up edges formed during conventional machining and formation of poor surface finish etc. Through non-traditional machining processes, machining of Al/SiC/Gr_p-MMCs encountered many problems by the researchers.

The problems encountered during processing of Al/SiC/Gr_p-MMCs in manufacturing industry through EDM are irregular material removal rate, requires large current, frequent wire break, unstable machining due to fluctuation of spark gap, very poor surface finish etc. Using non-conventional machining techniques such as Laser and Water Jet machining, can achieve a fairly high material removal rate(MRR), what would often be accompanied by some serious surface and sub-surface defects, which in many cases are unacceptable to the final finished product. These problems restricted the wide spread application of Al/SiC/Gr_p-MMCs in manufacturing, aerospace, and automotive industry.

Although still only few research papers are available on traditional and non-traditional machining of Al/SiC/Gr_p-MMC, hence a lot of applied research on traditional and non-traditional machining processes is required to explore the successful utilization of the process parameters during the non-traditional machining of Al/SiC/Gr_p-MMC. To explore the potential utilization of the non-traditional machining process in the area of Al/SiC/Gr_p-MMC machining, in-depth experimental analysis is to be carried out for the controlling various machining parameters e.g. pulse on time (T_{ON}), pulse peak current (IP), Duty cycle (τ), Gap voltage (Vg), Pulse pause time (T_{OFF}), Tool/ Electrode polarity etc. on the different machinability criteria like material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR), and other accuracy features so as to find out the optimal machining condition. To meet the above requirement of machining of advance metal matrix composite, the EDM machining method is to be employed.

II. LITERATURE REVIEW

In year 1927 MMC Materials began as "Mississippi Concrete and Material Company" in Jackson, Mississippi, formed by the company now known as "Dunn Investment Company" located in Birmingham. In 1932 – 1961 name changed to "Mississippi Materials Company" under President Ellis Hoffpauir. The field of Ai/SiC whisker composites began in the mid-1960s with the realization that whiskers or discontinuous fiber reinforcements can be competitive with continuous fiber reinforced material from the stand point of mechanical properties. Hibbered (1964), in a review presented in the introductory paper at the American Society for Metal Meeting on Fiber composite materials concluded: “There should be little or no solubility or other reaction between the matrix and the fiber, which should wet each other”.

This condition is satisfied most readily by one special group of composites based on directionally solidified eutectics. The principal advances since 1964 meeting have been largely in control of inter face between reinforcements and matrices that do not meet restriction. In their keynote address at American institute of Mining and Metallurgical Engineers symposium on metal matrix composites, Burte and Lynch (1969) identified filament matrix compatibility as the pacing area for development of the technology of these composites. Although these authors include both physiological as well as mechanical compatibility within this subject, the basic problem was identified as degradation resulting from chemical interaction. Thereafter, the high cost SiC whisker precluded the potential application of these composites to engineering application.

Lastly, with the availability of relatively inexpensive SiC produced mainly from rice hull, interest in Al-SiC composite since chemical, physical and mechanical properties were discussed by Divecha A.D.; Fishman S.G; and Karmarker S.D.; in 1981. Thereafter, began study on the machinability of Al/SiC/Gr_p composites for their potential industrial application. Since then a good number of researches are being made to machine Aluminum metal matrix composite using various machining process in the practical material machining field. Few of the research works are reviewed and reported in the area are described here in after.

Manna A. and Bhattacharyya B. (2003) studied the machinability of Al/SiC-MMC. The impact of machining parameters such as cutting speed, feed and depth of cut on the cutting force and surface roughness criteria were investigated. Through SEM micrographs BUE and chip formation at different sets of experiments were examined. Author concluded that flank wear rate is aversively proportional to cutting speed due to generation of high cutting force and formation of BUE.

M.Kiyak and O.Cakir (2007), studied the influence of EDM parameters on machining of tool steel. Experiments concluded that surface roughness increased with increasing pulse current and pulse time and impact of pulse off time was insignificant.

Eckart Uhlmann and Markus Roehner (2008), examined that due to short pulse duration the electrode wear rate is high in Micro EDM. They investigated the influence of electrode material on tool electrode wear and surface formation process.

S.L.Chen, M.H.Lin, S.F.Hsieh and S.Y.Chiou (2008), studied the EDM process for SUS 304 and examined that MRR is directly proportional to current and pulse duration. Electrode wear increased up to 80 µs then start decreasing with increase in pulse duration.

Ozlem Salman and M.Cengiz Kayacan (2008) examined the impact on two different material’s surface roughness of Tungsten and graphite electrode. Powder metal material yields smaller roughness under similar parameters.

H.Zarepour and A.Fadaei Tehra (2007) nistudied the machinability of tool steel. The impact of machining parameters such as On-Time and current on tool wear rate. There is negligible impact of voltage on tool wear, which increases with increase in energy then decreases.

Che Chung Wang and Biing Hwa Yan (1999), studied the impact of machining parameters such as current, pulse on time, pulse off time, Electrode polarity, gap voltage and electrode material. Experimentally it was found that pulse on time have direct impact on surface roughness and tool wear rate. Material removal rate increases with increase in current.

S.Clijsters and K.Liu (2010), examined the influence of current pulse on-time, pulse off-time, polarity (electrode) and gap voltage on surface roughness, tool electrode wear and material removal rate and found experimentally that surface roughness increases with increase in current, pulse on-time and gap voltage but decrease with increase in pulse off-time. On the other hand tool wear and MRR are inversely proportional to current.

Yan-Cherng Lin and Ho-Shiun Lee (2008), studied the impact of pulsed current, pulse on time, duty cycle and polarity on SR, TWR and MRR. According to experiment results surface roughness is low at low current value but gives minor tool wear, which is higher at low pulse duration. MRR increases with increase in current and pulse duration.

Manna A. and Bhattacharyya B. (2004), experimentally investigated the influence of cutting conditions on surface finish during turning of Al/SiC-MMC. In this study, the taguchi method, a powerful tool for experiment design was used to optimize the cutting parameters for effective turning of Al/SiC-MMC using a fixed rhombic tooling system.

Manna A. and Bhattacharyya B. (2006), experimentally studied the machinability of Al/SiC-MMC by utilizing CNC-Wire cut EDM. Authors studied the various parameters of WEDM during machining and established the optimum combination of WEDM parameters for different performance criteria. It was concluded that low input pressure of dielectric is not sufficient to remove the reinforced particles during machining. Open gap voltage and pulse on-time are the most significant and influencing machining parameters for controlling the material removal rate.

Manna A. and Bhattacharyya B. (2003), experimentally investigated the influence of cutting parameters of CNC-WEDM during machining of Al/SiC-MMC. Taguchi quality design was explore to optimize WEDM parameters and suggested optimal parametric combination for better machining quality.

K.Kanlayasiri and S.Boonmung (2007), experimentally investigated the influence of experimental wire EDM machining variables on surface finish of die steel. Authors took various levels of machine parameters such as current, pulse on-time, pulse off-time and wire tension into account and found surface roughness is directly proportional to pulse on-time and pulse peak current and have insignificant impact of other variables.

Seiji Kumagai and Naoki Sato (2007), studied the fabrication of narrow hole through encased WEDM and found that machining rate is quite better at low pulse width (Wp) while higher value of pulse width give low machining rate at higher tool wear rate. Author found that the optimum results are at Wp = 40 µs, which gave 56% more machining rate than at Wp= 20 µs.

Eberhard and Dinesh Rakwal (2007), experimentally investigated that surface roughness is a function of capacitance. Author experimentally proved that at low capacitance (3.5 ηF) surface roughness is low and is maximum at high capacitance (68.5 ηF). They found that in comparison to capacitance other parameters have insignificant impact on surface roughness.

Mohammad Jafar Haddad and Alireza Fadaei Thrani (2008), experimentally investigated the influence of cutting conditions on surface finish, roundness and material removal rate of tool steel. Authors used factorial design in DOE (Design of experiment) technique to find the impact of machining parameters. It was concluded that surface roughness and material removal rate is directly proportional to power and voltage and are inversely proportional to pulse on-time and spindle rotational speed. Author then used regression analysis to generate a model of high stability.

Mu-Tian Yan and Yi-Peng Lai (2007), experimentally investigated the influence of cutting conditions on surface finish during fine finish power supply. Author concluded that higher value of capacitance results in higher energy and thus contributes to longer discharge duration. The peak current increases with increase of pulse on-time, which gives high surface roughness. For fine finish wire tension (WT) must be more.

G. Rajaram, S.Kumaran (2010), studied the behavior of composite at higher temperature by adding graphite to the composite. The Al–Si/graphite composite can perform well up to 300˚C, but the alloy can withstand till 250˚C. During direct metal to metal contact, the graphite particles from composite pin surface forms a thin tribo film between surfaces. Tearing and formation of oxide layer and graphite film is a continuous process which results in decrement of wear rate for composite, when the operating temperatures are increased.

S. Suresha, B.K. Sridhara (2010), found experimentally that addition of Grp particulates facilitates easy machining and results in reduced wear of Al–Grp composites compared to Al alloy. But high amount of Grp may result in increase of wear due to decrease in fracture toughness with increase in % reinforcement of Grp particulates. In tribological applications demanding similar strength requirement, Al–SiC–Grp hybrid composites are better substitutes to Al–Grp and Al–SiC composites owing to improved wear resistance as a result of combined reinforcement of SiC and Grp particulates

Leng Jinfeng, Jiang Longtao, Wu Gaohui, Tian Shoufu, Chen Guoqin (2009), studied that with the addition of graphite, the friction coefficient of SiC/Al composites decreases and the wear resistance is significantly increased by 170 to 340 times. Moreover, the wear loss of counter face steel is decreased by a factor of about 2/3. The wear resistance of SiC/Grp/Al composites increases with the increase of the graphite particle size. The improvement of wear resistance is mainly attributed to the enhancement of integrity of lubrication tribo-layer composed of a complex mixture of iron oxides, graphite as well as fractured SiC particles and some fine particles containing aluminum.

Zhang, Lavernia (1994), studied the effect of SiC and Gr_p particulates on the resultant damping behavior of 6061 A1 MMCs. The MMCs were processed by spray atomization and deposition technique and the damping characterization was conducted on a dynamic mechanical thermal analyzer. It was shown that the damping capacity of 6061 A1 could be significantly improved by the addition of either SiC or Graphite through spray deposition processing.

Prakash.C.H, Pruthviraj R.D (2011), studied that the major drawbacks of these Zn-Al based composites are reduced conductivity and poor machinability. To overcome this, efforts are on to make use of a soft phase such as graphite as a additional reinforcement to the conventional Zn-Al based hard reinforced composites. Graphite being a solid lubricant can improve the machinability of the composites. Furthermore, graphite possess excellent thermal and electrical conductivity thereby, can improve the conducting capability of Zn-Al composites.

M.L.TedGuo, Chi.-Y.A.Tsao (2002), found experimentally that The graphite agglomerates much less in composites with coated Gr–Ni particles than in composites with non-coated Gr particles. Coefficient of thermal expansion decreases significantly with the amount of Gr–Ni addition. The fracture energy decreases monotonously as the amount of Gr–Ni addition increases. Wear debris become smaller, which cause smaller electric contact resistance, as the amount of Gr–Ni addition increases. Seizure occurs for monolithic aluminum alloy, but no seizure occurs for Al/SiC and Al/SiC/Gr–Ni composites. The friction coefficient and its fluctuations decrease as the percentage of Gr–Ni addition increases. Graphite released from the composites bonds to the wear surfaces of the composites and counter parts. Due to the ‘‘composite effects’’, wear rates of both the composite and counterpart increase as the amount of Gr–Ni addition increases up to 5% Gr–Ni addition, then drop for 8% Gr–Ni addition. The wear rates of all the composites with Gr–Ni additions are higher than the wear rate of base Al/SiC material with no Gr–Ni addition.

L. Krishnamurthy, B.K. Sridhara, D. Abdul Budan (2011), present result of an experimental investigation on the comparative machinability of aluminum-silicon carbide composites and aluminum-graphite-silicon carbide hybrid composites during turning using carbide tool inserts. The experiments have been carried out based on central composite design of experiments approach. The influence of machining parameters viz. cutting speed, feed and depth of cut on the resultant force has been analyzed statistically. It is established that hybrid composites have better machinability when compared to aluminum-silicon carbide composites.

Manchang Gui, Suk Bong Kang shows that production of aluminum matrix composite coatings containing SiCp, as well as aluminum hybrid composite coatings containing SiC and graphite particles was explored by plasma spraying of premixed powders onto a solid aluminum alloy substrate. In both Al+SiC and Al+SiC+Gr composite coatings, SiC particles have a quite uniform distribution, while the distribution of graphite particles is inhomogeneous. No visible interval between the coating and the substrate can be found, which proved a good compatibility and intimate bonding between them. And no interfacial reaction products can be seen.

S. Suresha, B.K. Sridhara (1982), shows that Aluminum matrix composites with multiple reinforcements (hybrid AMCs) are finding increased applications because of improved mechanical and Tribological properties and hence are better substitutes for single reinforced composites. Dry sliding wear tests have been performed to study the influence of Gr particulates, load, sliding speed and sliding distance on the wear of hybrid composite specimens with combined % reinforcement of 2.5%, 5%, 7.5% and 10% with equal weight % of SiC and Gr particulates. Experiments are also conducted on composites with % reinforcement of SiC similar to hybrid composites for the sake of comparison. Parametric studies based on design of experiments (DOE) techniques indicate that the wear of hybrid composites decreases from 0.0234 g to 0.0221 g as the % reinforcement increases from 3% to 7.5%. But the wear has a tendency to increase beyond % reinforcement of 7.5% as its value is 0.0225 g at.% reinforcement of 10%. This trend is absent in case of composites reinforced with SiC alone. The values of wear of these composites are 0.0323 g, 0.0252 g and 0.0223 g, respectively, at. % reinforcement of 3%, 7.5% and 10% clearly indicating that hybrid composites exhibit better wear characteristics compared to composites reinforced with SiC alone.

Jinfeng Leng, Gaohui Wu, Qingbo Zhou, Zuoyong Dou, XiaoLi Huang (2008), found that SiC/Gr/Al composites were fabricated by squeeze casting with graphite volume fractions of 3–7% and particles size of 1, 6, 10, 20 and 70 μm. No Al_4C_3 brittle interfacial product could be detected by transmission electron microscopy. With increasing volume fraction and particle size of graphite, the tensile strength (σb) decrease from 420 to 235 MPa and the elastic modulus (E) decrease from 166 to 116 GPa. These changes were in close accordance with the linear function: $E = 224\sigma b + 61{,}695$.

Jinfeng Leng, Longtao Jiang, Qiang Zhang, Gaohui Wu, Dongli Sun and Qingbo Zhou (2008), found experimentally that The effect of flaky graphite particles [with volume fraction (vf) 3–7%] on machinability and mechanical properties of SiC/Al composites were investigated. Results showed that the machinability was improved greatly with the increasing vf of graphite particles. When the vf of graphite particles was 7%, the tool life was prolonged by 130%, and the tensile strength and elastic modulus of SiC/Gr/Al composite were 365 MPa and 144 GPa, respectively. The presence of flake graphite particle acted as solid lubrication and promoted chip formation during cutting, resulting in an improved machinability.

Farshad Akhlaghi, S. Mahdavi (2011), in Al/Gr/SiC hybrid composites graphite acts as a solid lubricating agent and lowers the friction coefficient. However, it reduces the mechanical properties of the composite. The presence of hard SiC particles in these hybrid composites increases the hardness and strength and compensates for the weakening effects of graphite. Powder metallurgy (P/M) is an important processing technique for processing of these MMCs but requires a relatively long mixing time for obtaining a uniform distribution of graphite and SiC particles in the matrix alloy. In the present study for the first time a new method, namely "in situ powder metallurgy (IPM)" is applied for preparation of Al/SiC/Gr hybrid composites. The Al/Gr/SiC compacts were prepared by cold pressing of different powder mixtures and after sintering, the effects of SiC content on the density, microstructure, hardness and wear properties of the resultant hybrid composites was investigated.

Adrian Iosub, Eugen Axinte, Florin Negoescu (2010), gave the influence of the most relevant parameters of Electrical Discharge Machining over material removal rate, electrode wear and machined surface quality of a hybrid metal matrix composite material (Al/SiC) has been carried out. The material used in this study is aluminum matrix composite reinforced with 7 % SiC and 3.5 % graphite. The hybrid composite was machined using 27 brass tools with Ø = 3.97 mm. Different pulse on-times (t_{on}), pulse off time (t_{off}) and peak current values (Ip) was used for each electrode. For the experiments, a full factorial design was used. Regression analysis was applied for developing a mathematical model. The hybrid SiC/Al composite material can easily be machined by EDM and a good surface quality can be obtained by controlling the machining parameters.

III. DISCUSSION

From the above literature survey, it is clear that there is essential to select proper machining process for effective machining of hybrid Al/SiC/Gr_p-MMC. As such no sufficient number of literature on machining of hybrid Al/(SiC_p + Gr_p)-MMC is available, but from the published research work it is clear that the Al/SiC-MMC machining is one of the major problem, which resist its wide spread application in industry. The problems encountered during Al/SiC-MMC machining are.

1. Rapid Tool Electrode wear rate
2. Irregular material removal rate (MRR).
3. Requirement of large pulse current values.
4. Difficult to cut very complex and complicated shape or geometrical profile.
5. Very poor surface finish and low machining rate.
6. Frequent stoppages of metal removal during machining.
7. SiC particles in the particulate reinforced), which behaves like a cutting edge during machining of Al/SiC/Gr_p-MMC. aluminum matrix composite are harder than Tungsten carbide (WC).

VI. CONCLUSION

From the above literature survey, it is clear that there is essential need to select proper machining process for effective machining of hybrid Al/SiC/Gr_p-MMC. As such no sufficient number of literature on machining of hybrid Al/(SiC_p + Gr_p)-MMC is available, but from the published research work it is clear that the Al/SiC-MMC machining is one of the major problem, which resist its wide spread application in industry. The technique of EDM can help us to obtain the desired results.

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