Experimental Investigation on Crashworthiness Characteristics of E-Glass–Lycal Composite Tube and Local Product Aluminum Tube Using Quasi-Static Crushing Test

Dony Hidayat [1, a)], Abian Nurrohmad[1, b)], Afid Nugroho[1, c)], Lathifa R. Isna[1, d)]

[1]*Aeronautic Technology Center, National Institute of Aeronautics and Space (LAPAN), Indonesia*
Jl. Raya LAPAN, Rumpin, Sukamulya, Rumpin, Bogor, Jawa Barat.

[a)]Corresponding author: dony.hidayat@lapan.go.id
b)abian.nurrohmad@lapan.go.id
c)afid.nugroho@lapan.go.id
d)lathifa.rusita@lapan.go.id

Abstract. This paper investigates the crashworthiness characteristics of material applicated in LAPAN's UAV (E-glass–Lycal & Al) under axial quasi-static crushing. The effects of ply numbers (5, 7, 9) of polimer matrix composites (PMCs) tube on crashworthiness have been studied. Subject to axial crushing the experimental tests exhibit that all of empty circular PMCs specimens undergo a progressive end collapse. E-glass–Lycal composite tube has specific energy absorption (SEA) increasing from 13.63 J/g to 23.74 J/g, and the local product aluminum tube has SEA of 32.93 J/g.

INTRODUCTION

The use of composite materials in the automotive and aerospace industries is quite developed nowadays.[1,2] The advantages of using polymer matrix composites (PMCs), compared to metal, ceramic, and plastic, are high specific stiffness and strength, low cost, lightweight, flexibility in design, parts consolidation, dimensional stability and corrosion resistance.[3] These advantages are needed to be used as UAV structure, since it can increase the fuel efficiency and improve the structure performance. Some components of LAPAN's UAV series utilize composite materials and aluminum tube.[4,5]

Many authors have demonstrated the structure made of composite materials that has high specific energy absorption capability,[6,7] with a value above 41 J/g (carbon fiber). Libo Yan and Nawawi Chouw[8] conducted experimental investigation on the crashworthiness characteristics of natural flax fiber reinforced epoxy composite circular tubes. The test results indicated that the flax fiber reinforced epoxy composite tube has the potential to be used as an energy absorber. K. Vinayagar and A. Senthil Kumar[9] presented multiobjective optimization of parameters that affect crashworthiness characteristics of bi-tubular structures using Taguchi method with grey relational analysis. The test results show that the crushing behaviors of bi-tubular structures with various combinations were fairly significant. A. Al Antali *et al.*[10] investigated the energy-absorbing characteristics of a lightweight honeycomb core containing embedded carbon fiber reinforced plastic (CFRP) tubes. Initial tests are undertaken on the plain aluminum honeycomb material in order to characterize its specific energy absorption (SEA) capability and to identify the prevailing failure mechanisms. Tests are conducted on honeycomb cores reinforced with increasing numbers of composite tubes in order to establish the influence of varying the density of the tubular array on the measured SEA. Tests on the plain aluminum honeycomb cores resulted in the characteristic plastic wrinkling of the cell walls, yielding an average value of SEA of 14 kJ/kg. Embedding CFRP tubes into the honeycomb served to greatly enhance the energy-absorbing properties of the core, with quasi-static values of SEA reaching as high as 105 kJ/kg.

This paper studies the crashworthiness characteristics of empty PMCs tube and aluminum tube specimens. Both materials are used for LAPAN UAVs under quasi-static axial compression tests.

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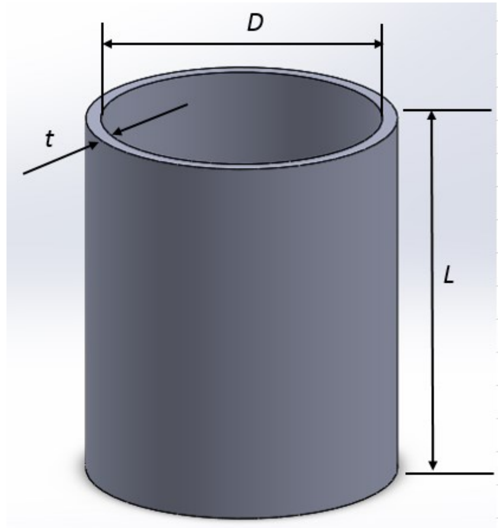

FIGURE 1. Schematic of tube parameter

METHODS

Specimen Preparation

The circular PMCs tubes have been made of E-glass EW 185 fiber laminates with Lycal utilize hand lay-up method. In this study, only ply numbers parameter of empty PMCs tubes was considered to investigate the crashworthiness characteristics of the PMCs tubes.

Figure 1 illustrates the geometries of the circular tube with the dimensions length (L), wall thickness (t), and outer diameter (D). The PMCs tubes were made of three different ply numbers (5-ply, 7-ply and 9-ply) for investigating the effects of ply numbers on the crashworthiness.

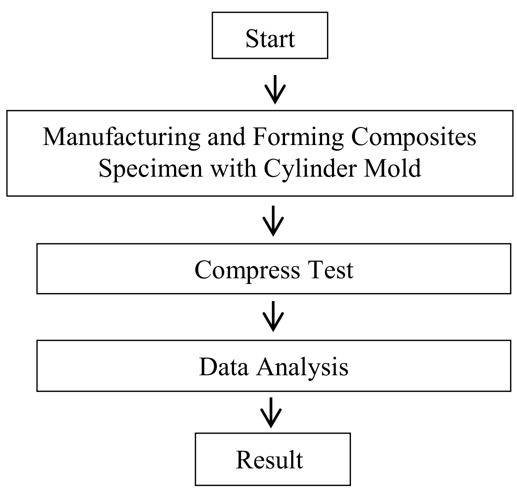

FIGURE 2. Flowchart of research

The tensile behavior of E-glass EW 185 fiber-reinforced polymer GFRP laminates with Lycal has already investigated by Kosim *et al.*,[11] the test results showed the ultimate tensile strength value of 260.98 MPa, and average modulus elasticity of 8.66 GPa.

TABLE 1. Material properties of GFRP.

Designation	**Density (kg/m3)**	**Young's Modulus (GPa)**	**Ultimate Tensile Stress (MPa)**
E-glass–Lycal	1.51	8.66	260.98

Quasi-Static Compressive Test

Compressive testing of the specimens was performed by applying uniaxial quasi-static compressive forces using Tensilon RTF 2410 universal test machine with loading capacity of 100 kN. The crosshead speed used was 5 mm/min. The crushing load and its corresponding displacement were recorded by a data acquisition system. The deformation behaviors of the tubular specimens were photographed during the quasi-static crushing process.

Crashworthiness Criteria

To measure the crashworthiness, several different criteria are often used, namely initial peak force (F_{max}), mean crushing force (F_{avg}), crash load efficiency (CFE), energy absorption (E_a) and specific energy absorption (SEA). The average crushing force (F_{avg}) is defined mathematically as:

$$F_{avg} = \frac{1}{d} \int_0^d F\ (\delta)\ d\delta \tag{1}$$

where d is the collapse distance, and $F\ (\delta)$ is the instantaneous crush force.

Crush force efficiency (CFE), defined as the ratio of the average crushing force (F_{avg}) to the initial peak force (F_{max}), is used to measure the uniformity of crushing force, as

$$CFE = \frac{F_{avg}}{F_{max}} \tag{2}$$

The higher the value of CFE, the better the crashworthiness performance.

The energy absorption (E_a), obtained by integrating the load–displacement curve during the loading process, mathematically described as

$$E_a = \int_0^d F\ (\delta)\ d\delta \tag{3}$$

The higher the energy absorption (E_a), the better the crashworthiness. To account for the effect of mass (weight), specific energy absorption (SEA) defined as

$$SEA = \frac{E_a}{m} \tag{4}$$

which is frequently used as one of most critical crashworthiness criteria.

RESULTS AND DISCUSSIONS

Three distinct failure modes of the brittle composite materials were observed during the quasi-static compression test, as classified in Mode I (progressive end-crushing mode), Mode II (unstable local tube wall buckling mode), and Mode III (mid-length collapse).[6] In this experiment, it was found that all the PMCs tubes failed in Mode I, as shown in Fig. 3.

TABLE 2. Results of GFRP and aluminum.

Specimen	Ply Number	D (mm)	L (mm)	m (g)	F_{max} (kN)	F_{avg} (kN)	CFE	E_a (J)	SEA (J/g)
E-glass–Lycal	5	25	50	6.77	5.38	2.64	0.49	92.34	13.63
E-glass–Lycal	7	25	50	10.08	7.45	5.97	0.80	208.98	20.73
E-glass–Lycal	9	25	50	11.4	8.66	7.88	0.91	275.65	23.74
Aluminum	-	23	50	8.8	12.36	8.23	0.67	288.15	32.93

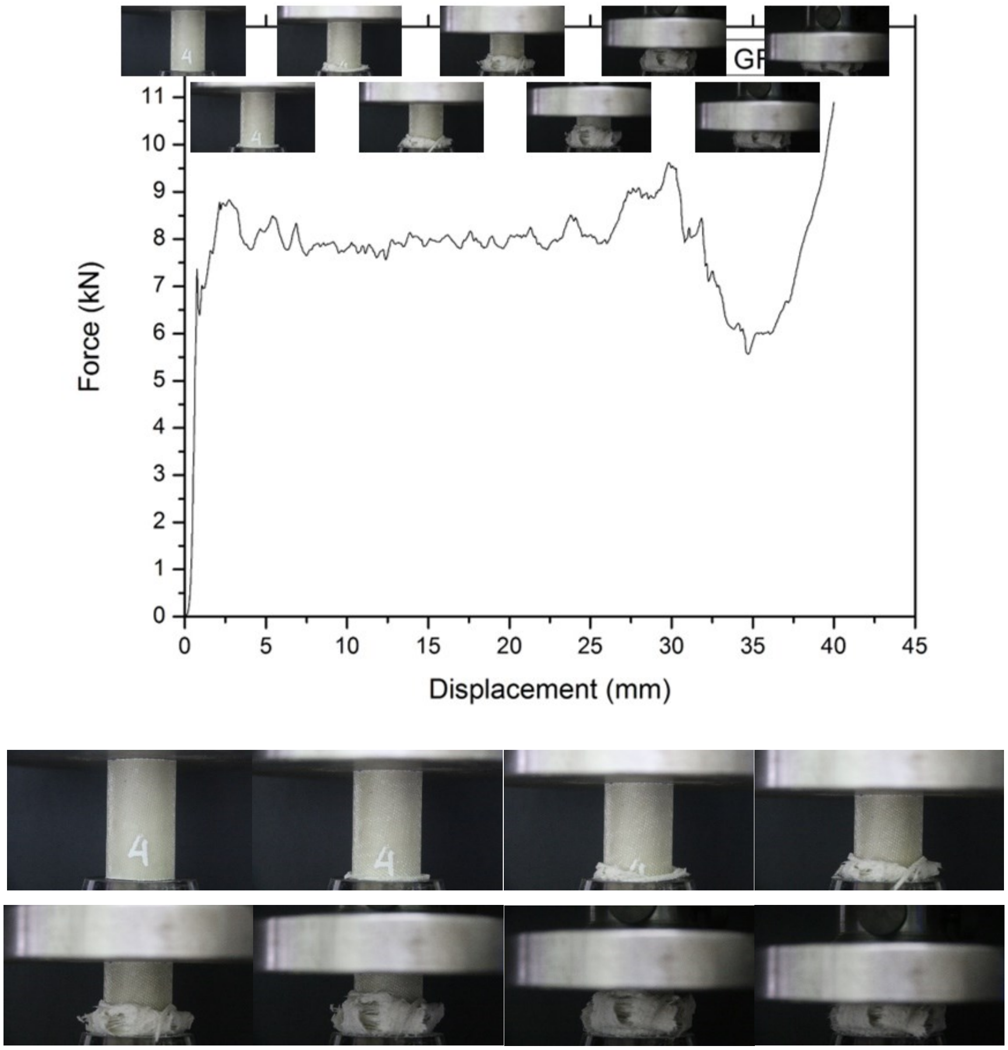

FIGURE 3. Sequential deformation of E-glass–Lycal composite

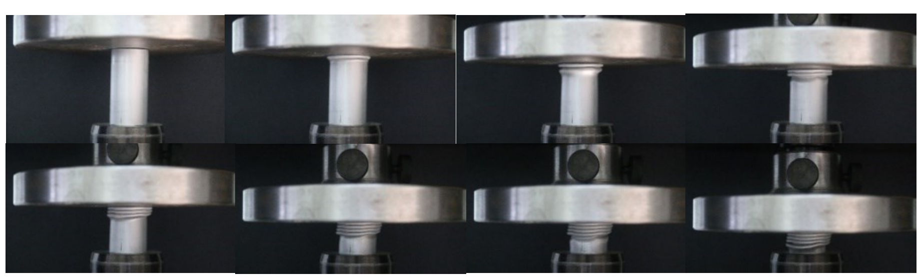

FIGURE 4. Sequential deformation of thin wall aluminum

FIGURE 5. Specimens after crushing test

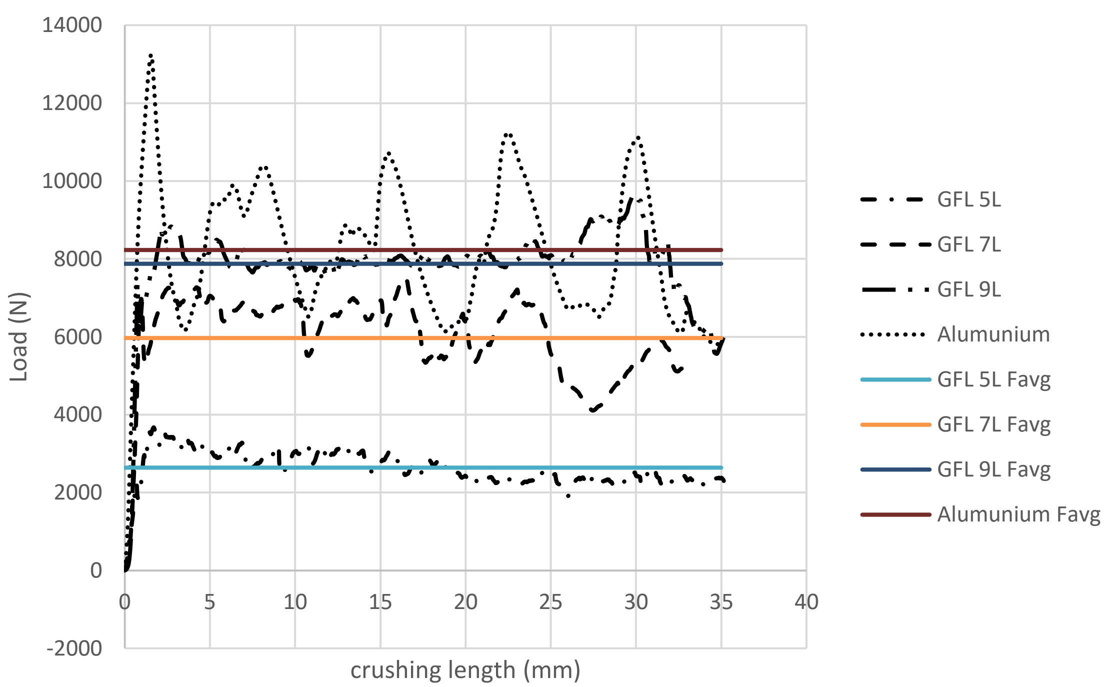

FIGURE 6. Load vs crushing length diagram of glass fiber composite and aluminum tube

Figure 6 shows the load vs crushing length of glass fiber composite and aluminum tube. The composite tube was made of 5, 7, and 9 plies. The fluctuative graphic shows that the more ply of the composite, the higher its average force average. The average force of aluminum tube is higher than the composite tube.

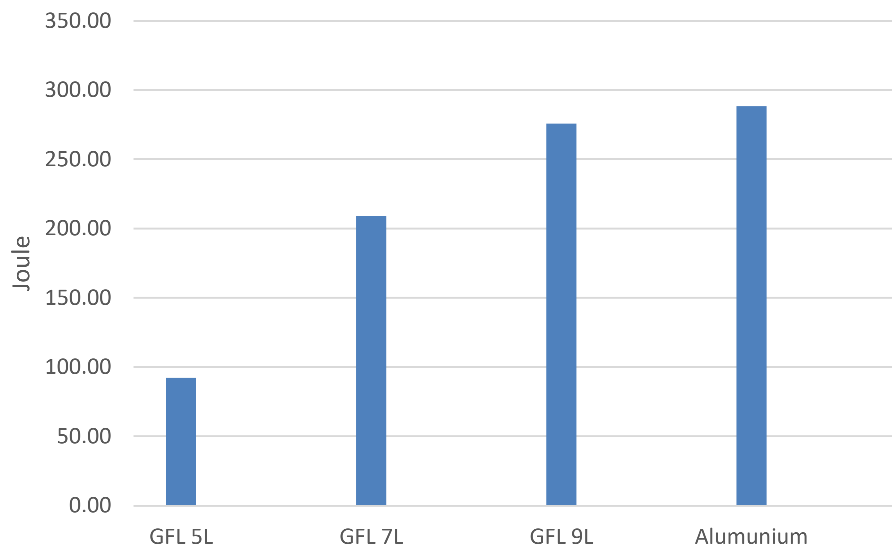

FIGURE 7. Energy absorption

Figure 7 shows that the more plies of composite tube, the higher the energy absorption. The aluminum tube has a little more energy absorption than the 9 plies of composite tubes. The theory of crashworthiness informs that the thicker the tube, the higher its energy absorption.

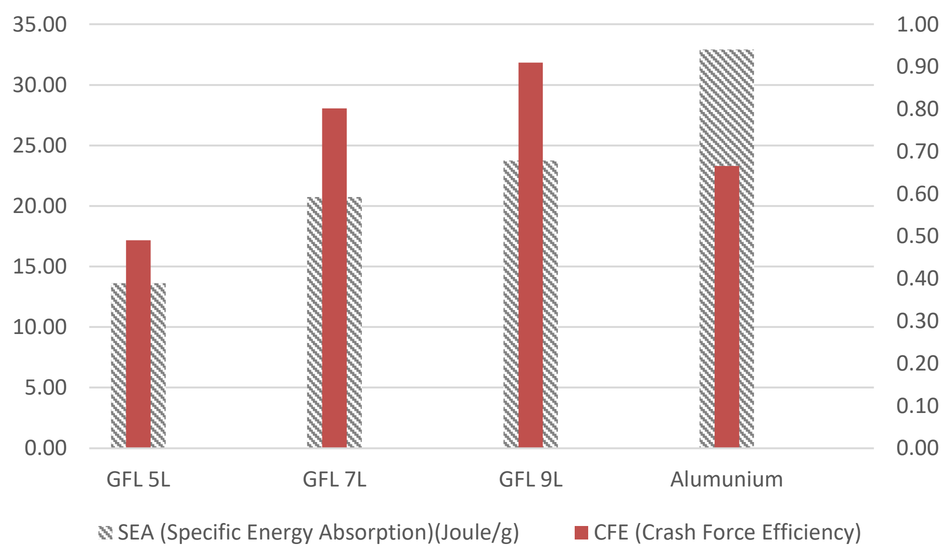

FIGURE 8. Comparison of the SEA and CFE of the specimens

Figure 8 shows the comparison of the SEA and CFE of all specimens. The specimen of GFL 9 plies has the highest CFE among all of the tube. The highest SEA value is on aluminum tube. From all of the composite tube, the more the ply, the higher its SEA value. It is also occured on the CFE value. The value of aluminum tube is relatively lower than the composite tubes. It is because the higher value of peak force that occured in aluminum tube.

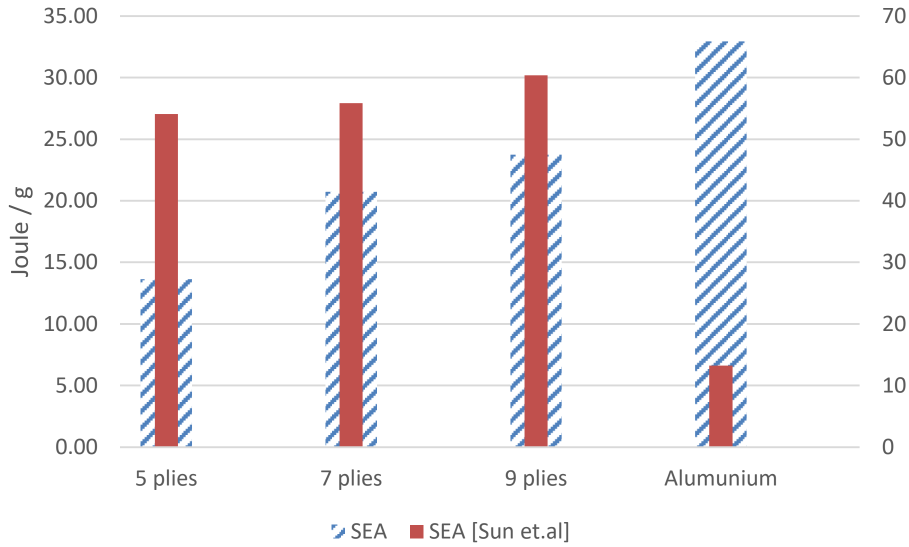

FIGURE 9. The comparison of SEA value with the results from Sun, *et al.*[6]

With the similarity of its ratio of length over the diameter, the experimental results were compared with the results from Sun *et al.*, as can be seen on the Fig. 9. The composite used in this research is E-glass fiber-reinforced polymer, while Sun, *et al.* used the carbon fiber-reinforced polimer. The value of the SEA of the composite from Sun, *et al*. is higher than this results because the performance of carbon fiber. The trend is also similar that the higher the number of plies also give results to the higher of the value of the SEA.

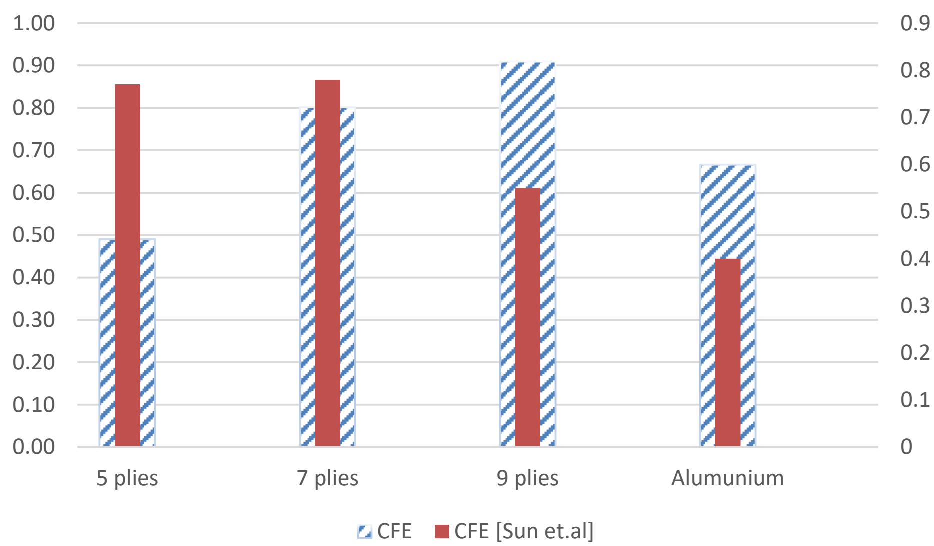

FIGURE 10. The comparison of CFE value with the results from Sun, *et al.*[6]

This research also compared the results of the CFE criterion over all specimens with the works of Sun, *et al.*[6] For aluminum tube, the value of CFE is higher than the results from Sun, *et al*. But for composite tube the results is the opposite. The results of this research, that used E-glass composite, is the higher number of plies gives effect of higher value of CFE, but from the results of Sun, *et al.* that used carbon fiber composite, the value of CFE decreased in effect of applying more plies on composite tubes.

CONCLUSION

From this research, it can be concluded that aluminum tube has higher SEA but has a lower value of CFE than composite tube. E-glass–Lycal composite tube has specific energy absorption (SEA) increasing from 13.63 J/g to 23.74 J/g and the local product aluminum tube 32.93 J/g. This research also compared the results of the work that has been done by Sun, *et al.* From this remarkable results, the suggestion to designer of UAV is in order to reach high MTOW (maximum take-off weight) the appropriate material is aluminum tube, considering its higher SEA value. The UAV possessing high MTOW also has more reaction force while it impacts with the ground, so the lower value of CFE on aluminum tube will not be a problem. For the UAV with low MTOW, it is more desired to use E-glass composite, because the energy that must be absorbed is not really big. The UAV with lower MTOW has smaller reaction force, so the value of CFE is needed.

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