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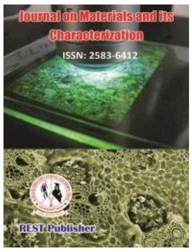

An Assessment of material selection Problem for piston in Automotive Engines Using the weighted sum model (WSM)

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Abstract: *An motor cylinder's pistons are a critical part. The producers are compelled to investigate using the optimal piston alloy in the combustion chambers due to intense rivalry among them. The most common materials used to make pistons are "steel, iron, and aluminium". The challenge of choosing an appropriate element for a machine part used in a particular structural application is challenging since the engineers must take a variety of aspects into account. When selecting the best applicant fabric for a specific application, developers must take into account a variety of properties, including "mechanical, physical, magnetic, electrical, thermal and radiation, surface characteristics, machinability, material cost, reliability, durability, recyclability, impact on the environment, availability, fashion, market trends, cultural aspects, etc.". This selection procedure is laborious and time-consuming. " Elegance, sentiments, and user-friendly design" are now the primary factors in today's choice of materials. In this study, eight potential piston composites' effectiveness is assessed using eight criteria. The best composites among the resources under consideration were selected using the "WSM method (Weighted Sum Method)", a multi-criteria choice procedure because no one material would merely fulfil all the needed features. The ranks of "Aluminum 2618-T61 is 3, Aluminum 4032-T6is 5, Aluminum A360.0-F die casting alloy is 6, Aluminum 6061-T6 is 4, Grey cast iron is 7, AISI 8660 steel is 2, AISI 4140 steel is 1 and Ductile iron grade 65–45-12is 8". The order preferred for materials is "AISI 4140 steel > AISI 8660 steel > Aluminum 2618-T61 > Aluminum 6061-T6 > Aluminum 4032-T6 > Aluminum A360.0-F die casting alloy > Grey cast iron > Ductile iron grade 65–45-12". "AISI 4140 steel, AISI 8660 steel and Aluminum 2618-T61" were discovered to be the best materials among the selected alternate materials, as per the Weighted Sum Method (WSM) technique. The people who make decisions' desire for choosing the best conveyor was significantly influenced by " high hardness, fatigue strength and modulus of elasticity, and low material cost of materials."*

1. INTRODUCTION

The choice of the individual components with the appropriate proportion and the development of the composition for "optimal density, mechanical strength, and wear performance" are the real-world issues that an expert or scientist in the automobile sector must deal with today. For many automotive applications, including piston cylinders, connecting rods, bearings, etc., aluminium-based alloys are the primary material used and are growing in importance [1]. Such polymers excel in automobile operations due to their "high strength-to-weight ratio, enhanced fatigue and creep capabilities, enhanced hardness and wear resistance, enhanced damping capability, and reduced coefficient of thermal expansion". Due to their excellent mechanical qualities, "aluminium silicon alloys" are presently the preferable materials to use when producing automobile parts (such as pistons) [2]. A fundamental reciprocating part of "cylinders, pumps, and engines is a piston". Its primary function is to invert the role of a pump and deliver energy from the liquid within the cylinder towards the crankshaft through the connecting rod. In a few circumstances, the piston within the cylinder also serves as a valve. Within a combustion process, the cylinder head is the fixed end, and the piston is the movable end. Due to the energies of the increasing flammable gases inside the chamber, the piston returns the favor and transfers the forces to "the connecting rod and crankshaft" [3]. The piston's primary responsibilities include "transmitting force first from working gas towards the working gas (power stroke) and vice versa (compression stroke), acting as the combustion chamber's variable lower bounding and sealing it, guiding the connecting rod, dissipating heat, supporting (in four-stroke engines) or controlling (in two-stroke engines) the charge exchange, supporting mixture formation, and housing the ring pack". As a result, the most frequent specifications are for "great structural strength, flexibility to working circumstances, low friction, low wear, low oil consumption, and low pollutant emissions". It should go without saying that choosing the right material for this piece is crucial to completing these duties [4]. As a result, during regular engine operation, the piston head is exposed to temperature strains, mechanical loads, and pressure changes. The main criteria that heavily influence the piston material selection process include the ability to function under a variety of operating situations, safety from "piston seizing, effortless operation, reduced weight, higher strength, less oil consumption, and less pollutant emission". Furthermore, the content that appears to be appropriate in one situation may not be in another. Due to the operating needs of various interior combustion engine layouts, aluminium silicon alloys are discovered to be the most appropriate piston component [5]. Pistons experience a significant amount of heat and structural stress throughout compression stroke. Thermal stress is only felt by the piston because of the considerable difference in temperature between both the cooling chambers and the piston tip. The structural load is caused by "the oscillating gas pressure and inertial forces" produced by the piston's return. " Piston side wear, head cracks, and other significant flaws" can be caused by thermo - mechanical stress [6,7]. Designers must come up with a compromise approach to address the tension between the product's quality and the properties they have taken into consideration to get the intended results from a given product. The choice of the material that is best appropriate for a particular application in the absence of opposing scenarios can be viewed as "a multicriteria decision-making (MCDM) problem" that must be solved using an analysis process [8,9]. Throughout its working cycles, a piston is subjected to high loads, which can cause a variety of piston defects, which eventually impair engine performance (POE) and cause engine seizing. Different piston materials, such as Aluminum LM series and specified Alloys, have been used by new researchers to prevent such a systemic collapse from happening in the piston. Different piston metals have mechanical properties that influence how well a piston performs. So, choosing the best piston substance for design requires consideration of several factors [10].

2. MATERIALS AND METHODS

A well-sound decision framework called MCDM assesses how options rank in the face of several, frequently at odds, selection criteria. The challenges are organized clearly and methodically using MCDM approaches. These traits make it simple for decision-makers to evaluate the issue and scale it follows their needs [11]. For MCDM situations, the assessment of the ordering of choices heavily relies on the analysis of data, including the weight and kind of features of the application and choice matrices. The real value given to these data has a significant impact on the outcomes produced by MCDM approaches. In MCDM challenges, input data is frequently erratic and variable. The findings generated using MCDM algorithms are not reliable since the input signal is unpredictable [12]. Since "the WSM" is the most well-known and straightforward MCDM strategy, using it is occasionally advised due to how easily it can be applied. WSM was selected for this job because it may be used by a variety of users, especially non-technical types. When organized ideas for identifying difficulties or systematic identification of possible ideas are made, this survey method is the one that is most frequently used in the SUMPs investigated since it is easy to explain to the participants in the community. However, it is crucial to keep in mind that for the approach to be solid and dependable, the weights utilized must be explained based on rational standards [13,14]. "The weighted sum approach (WSA) is a method" that seeks to identify the variant that offers the greatest benefit among the available options. This approach is based on computing the global usage value of the options while taking into consideration normalized criteria weights. There are essentially two steps to it. These two processes include normalization and overall total calculation (Taşabat et al., 2015). It has few objective restrictions and is the easiest and closest way to everyday application. If the units of measurement disagree, the qualification values are standardized, and after adding up the scores per the weight of each condition, the overall score for each possibility is determined [15,16].

Step 1. Design of “decision matrix and weight matrix”

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

The weight vector may be expressed as,

$$w_j = [w_1 \quad \cdots \quad w_n] \quad (2)$$

$$where \sum_{j=1}^{n} (w_1 \quad \cdots \quad w_n) = 1$$

Step 2. “Normalization of DM”

$$n_{ij} = \begin{cases} \frac{x_{ij}}{max.x_{ij}} & |\ j \in B \\ \frac{min.x_{ij}}{x_{ij}} & |\ j \in C \end{cases} \quad (3)$$

Where “n_{ij} is the normalized value of the i^{th} alternative for the j^{th} criterion, $max.x_{ij}$ and $min.x_{ij}$ are the maximum and minimum values of x_{ij} in the j^{th} column for the benefit (B) and cost criteria (C)” respectively.

Step 3. “Weighted normalized Decision Matrix.”

$$W_{n_{ij}} = w_j n_{ij} \quad (4)$$

Step 4. Ranking of alternatives

$$S_i^{WSM} = \sum_{j=1}^{n} w_j n_{ij} \tag{5}$$

Where, "S_i^{WSM} is the ranking score of the i^{th} alternative, w_j is the weight of the j^{th} the criterion". Then "the alternatives are ranked in descending order with the highest S_i^{WSM} being ranked highest" (17,18). To solve the relevant piston material picking issue and prove the usefulness of this technique in the new allocation of resources region, corresponding decision matrices, comprised of eight evaluation criteria ("Knoop hardness, Yield strength, Modulus of elasticity, Specific heat capacity, Machinability, Fatigue strength, Density and Material cost") and eight candidate alternatives ("Aluminum 2618-T61, Aluminum 4032-T6, Aluminum A360.0-F die casting alloy, Aluminum 6061-T6, Grey cast iron, AISI 8660 steel, AISI 4140 steel and Ductile iron grade 65–45-12") is considered. "Knoop hardness, Yield strength, Modulus of elasticity, Specific heat capacity, Machinability and Fatigue strength" are considered beneficial characteristics. "Density and Material cost" are considered non-beneficial characteristics.

3. ANALYSIS AND DISSECTION

TABLE 1. Decision matrix for piston material selection

Piston Materials	PMC1	PMC2	PMC3	PMC4	PMC5	PMC6	PMC7	PMC8
PM1	144	372	74.5	0.875	9	90	2.76	2.072
PM2	150	317	78.6	0.85	7	110	2.68	2.128
PM3	97	165	71	0.963	5	150	2.68	1.064
PM4	120	276	68.9	0.896	9	95	2.7	1.904
PM5	271	310	200	0.49	3	119	7.15	1.428
PM6	220	1551	205	0.475	5	335	7.85	0.854
PM7	369	1050	205	0.561	5	590	7.85	0.532
PM8	195	310	168	0.49	5	193	7.15	1.54

Table 1 shows "the initial decision matrix for the piston material selection". Here we consider eight candidate materials "Aluminum 2618-T61 (PM1), Aluminum 4032-T6 (PM2), Aluminum A360.0-F die casting alloy (PM3), Aluminum 6061-T6 (PM4), Grey cast iron (PM5), AISI 8660 steel (PM6), AISI 4140 steel (PM7) and Ductile iron grade 65–45-12 (PM8)" as alternates. After consideration, "Knoop hardness (PMC1) in HK, Yield strength (PMC2) in MPa, Modulus of elasticity (PMC3) in GPa, Specific heat capacity (PMC4) in J/g-°C, Machinability (PMC5), Fatigue strength (PMC6) in MPa, Density (PMC7) in g/cc and Material cost (PMC8) in USD/kg" are taken as evaluation parameters.

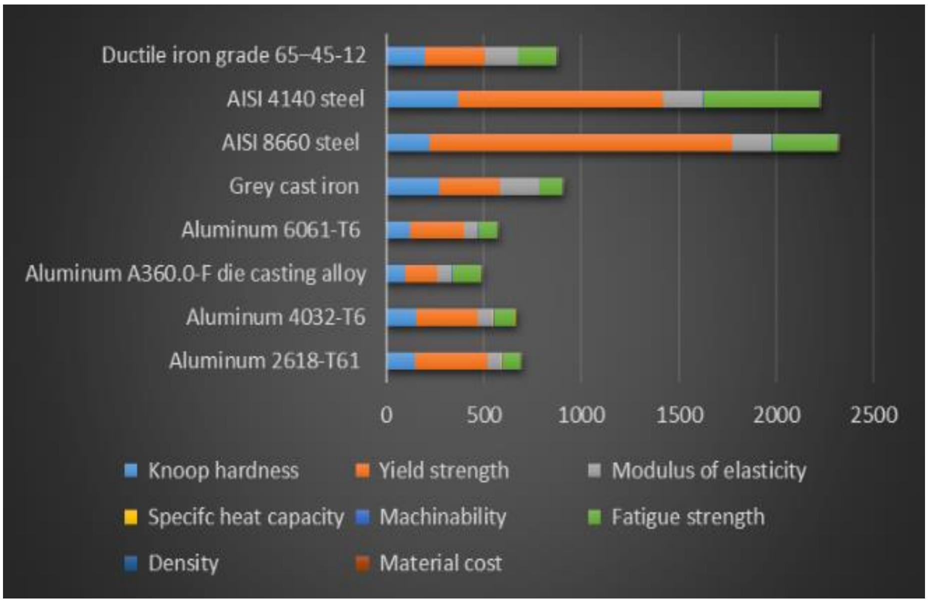

FIGURE 1. Piston material selection

Figure 1 illustrates "the initial decision matrix for the piston material selection". Here we consider eight candidate materials "Aluminum 2618-T61 (PM1), Aluminum 4032-T6 (PM2), Aluminum A360.0-F die casting alloy (PM3), Aluminum 6061-T6 (PM4), Grey cast iron (PM5), AISI 8660 steel (PM6), AISI 4140 steel (PM7) and Ductile iron grade 65–45-12 (PM8)" as alternates. After consideration, "Knoop hardness (PMC1) in HK, Yield strength (PMC2) in MPa, Modulus of elasticity (PMC3) in GPa, Specific heat capacity (PMC4) in J/g-°C, Machinability (PMC5), Fatigue strength (PMC6) in MPa, Density (PMC7) in g/cc and Material cost (PMC8) in USD/kg" are taken as evaluation parameters.

TABLE 2. Normalized matrix

0.3902	0.2398	0.3634	0.9086	1.0000	0.1525	0.9710	0.2568
0.4065	0.2044	0.3834	0.8827	0.7778	0.1864	1.0000	0.2500
0.2629	0.1064	0.3463	1.0000	0.5556	0.2542	1.0000	0.5000
0.3252	0.1779	0.3361	0.9304	1.0000	0.1610	0.9926	0.2794
0.7344	0.1999	0.9756	0.5088	0.3333	0.2017	0.3748	0.3725
0.5962	1.0000	1.0000	0.4933	0.5556	0.5678	0.3414	0.6230
1.0000	0.6770	1.0000	0.5826	0.5556	1.0000	0.3414	1.0000
0.5285	0.1999	0.8195	0.5088	0.5556	0.3271	0.3748	0.3455

Table 2 shows “the normalized array for material properties of alternative materials”. This is calculated using equation 3 for beneficial criteria (“Knoop hardness, Yield strength, Modulus of elasticity, Specific heat capacity, Machinability and Fatigue”) and non-beneficial criteria (“Density and Material cost”).

TABLE 3. Weight Matrix

0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 3 shows “the weight distributed among the eight evaluation parameters” according to equation 2 and the sum of the weight distributed among evaluated characteristics is one.

TABLE 4. Weighted Normalized Matrix

0.0488	0.0300	0.0454	0.1136	0.1250	0.0191	0.1214	0.0321
0.0508	0.0255	0.0479	0.1103	0.0972	0.0233	0.1250	0.0313
0.0329	0.0133	0.0433	0.1250	0.0694	0.0318	0.1250	0.0625
0.0407	0.0222	0.0420	0.1163	0.1250	0.0201	0.1241	0.0349
0.0918	0.0250	0.1220	0.0636	0.0417	0.0252	0.0469	0.0466
0.0745	0.1250	0.1250	0.0617	0.0694	0.0710	0.0427	0.0779
0.1250	0.0846	0.1250	0.0728	0.0694	0.1250	0.0427	0.1250
0.0661	0.0250	0.1024	0.0636	0.0694	0.0409	0.0469	0.0432

Table 4 shows “the weighted normalized matrix for piston selection problem for selected candidate materials”. It is calculated according to equation 4 using Tables 2 and 3.

TABLE 5. Preference Score

Materials	Preference Score
Aluminum 2618-T61	0.53530
Aluminum 4032-T6	0.51140
Aluminum A360.0-F die-casting alloy	0.50317
Aluminum 6061-T6	0.52534
Grey cast iron	0.46264
AISI 8660 steel	0.64715
AISI 4140 steel	0.76956
Ductile iron grade 65–45-12	0.45745

Table 5 shows “the preference score value for the alternate candidate materials for the piston selection problem”. It is calculated according to Equation 5 using Table 4. The preference score value for “Aluminum 2618-T61 is 0.53530, Aluminum 4032-T6 is 0.51140, Aluminum A360.0-F die casting alloy is 0.50317, Aluminum 6061-T6 is 0.52534, Grey cast iron is 0.46264, AISI 8660 steel is 0.64715, AISI 4140 steel is 0.76956 and Ductile iron grade 65–45-12 is 0.45745”.

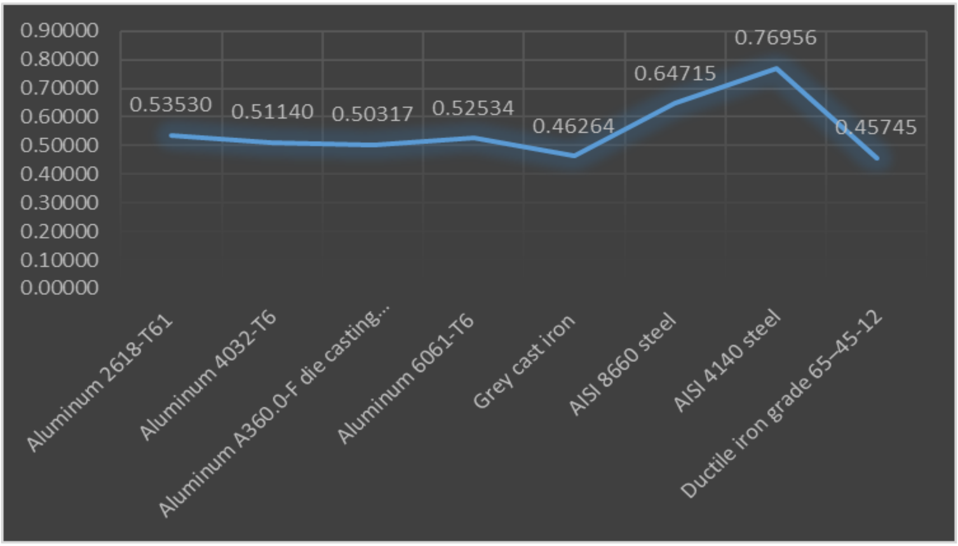

FIGURE 2. Preference Score

Figure 2 shows the illustration of "the preference score value for the alternate candidate materials for the piston selection problem". It is calculated according to Equation 5 using Table 4. The preference score value for "Aluminum 2618-T61 is 0.53530, Aluminum 4032-T6 is 0.51140, Aluminum A360.0-F die casting alloy is 0.50317, Aluminum 6061-T6 is 0.52534, Grey cast iron is 0.46264, AISI 8660 steel is 0.64715, AISI 4140 steel is 0.76956 and Ductile iron grade 65–45-12 is 0.45745".

TABLE 6. The Rank

Materials	Rank
Aluminum 2618-T61	3
Aluminum 4032-T6	5
Aluminum A360.0-F die-casting alloy	6
Aluminum 6061-T6	4
Grey cast iron	7
AISI 8660 steel	2
AISI 4140 steel	1
Ductile iron grade 65–45-12	8

Table 6 shows "the rank alternate materials selected for piston selection using the Weighted Sum Method (WSM)". Here the ranks of "Aluminum 2618-T61 is 3, Aluminum 4032-T6is 5, Aluminum A360.0-F die casting alloy is 6, Aluminum 6061-T6 is 4, Grey cast iron is 7, AISI 8660 steel is 2, AISI 4140 steel is 1 and Ductile iron grade 65–45-12is 8".

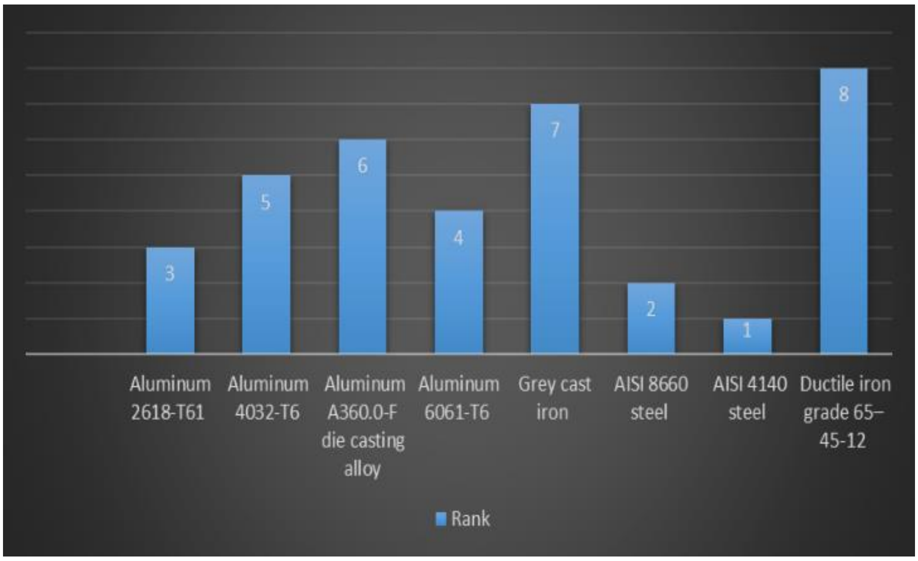

FIGURE 3. The Rank

Figure 3 shows the graphical representation of "the rank alternate materials selected for piston selection using the Weighted Sum Method (WSM)". Here the ranks of "Aluminum 2618-T61 is 3, Aluminum 4032-T6is 5, Aluminum A360.0-F die casting alloy is 6, Aluminum 6061-T6 is 4, Grey cast iron is 7, AISI 8660 steel is 2, AISI 4140 steel is 1 and Ductile iron grade 65–45-12is 8". The order preferred for materials is "AISI 4140 steel > AISI 8660 steel > Aluminum 2618-T61 > Aluminum 6061-T6 > Aluminum 4032-T6 > Aluminum A360.0-F die casting alloy > Grey cast iron > Ductile iron grade 65–45-12". "AISI 4140 steel, AISI 8660 steel and Aluminum 2618-T61" were discovered to be the best materials among the selected alternate materials, as per the Weighted Sum Method (WSM) technique.

4. CONCLUSION

The rising use of automobiles has led to high demand for automotive parts. The higher performance and lower cost of these parts are the causes of the growing market. To reduce the time required to release new goods, Innovation and certification experts should build vital aspects as quickly as feasible. Mastering new technology and swift assimilation in the advancement of innovative products are therefore necessary. "A piston is a part of IC engines" that reciprocate. It is the working part, housed by cylinders, and is sealed off from the atmosphere by piston rings. The "function of a piston rod and/or connecting rod in an engine" is to transmit force from "the expanding gas in the cylinder to the crankshaft". The cyclic compressed gases and inertial forces that the piston experiences while in operation as an integral component of an engine can lead to fatigue failure, including the wear on the sides and fractures in the heads and crowns. An essential mechanical element that has an impact on reversible engine efficiency is piston. Therefore, choosing the best material for pistons will become a duty that producers must complete. In this study, eight potential piston composites evaluation is conducted using eight criteria. The best composite from among the elements under consideration was selected using "the WSM method (Weighted Sum Method)", a multi-criteria choice procedure because no one component could simply satisfy all the needed features. The ranks of "Aluminum 2618-T61 is 3, Aluminum 4032-T6is 5, Aluminum A360.0-F die casting alloy is 6, Aluminum 6061-T6 is 4, Grey cast iron is 7, AISI 8660 steel is 2, AISI 4140 steel is 1 and Ductile iron grade 65–45-12is 8". The order preferred for materials is "AISI 4140 steel > AISI 8660 steel > Aluminum 2618-T61 > Aluminum 6061-T6 > Aluminum 4032-T6 > Aluminum A360.0-F die casting alloy > Grey cast iron > Ductile iron grade 65–45-12". AISI 4140 steel, AISI 8660 steel and Aluminum 2618-T61 were discovered to be the best materials among the selected alternate materials, as per the Weighted Sum Method (WSM) technique.

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