A Review-Weight Reduction in Automobile Bodies Using Magnesium Alloys

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ABSTRACT

Reduction in the vehicle weight is the important approach in the fuel economy. Magnesium is among the attractive materials available with low density and good strength properties. Magnesium alloys are the lightest of all structural material and they have tremendous weight saving potential. In structural applications where weight plays major role, usage of magnesium alloys has considerably increased over past decade. Its recyclability property have given it an edge. The use of magnesium alloys was limited in early years for automotive industry but now a days the awareness for fuel economy and reduce the emissions through reduction in CO_2 makes the material attractive for use. This paper highlights the benefits of magnesium, its alloy materials, manufacturing processes, its applications in automobile industries.

Keywords: Magnesium, automotive, light weighting.

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1. Introduction:

In 1808, Sir Humphrey Davy has discovered the material, and in metallic form was discovered by Antoine Bussy in 1831. It was originated from the Greek word from the district of Thessaly called Magnesia. Davi's suggestion was 'Magnium' but later on it became 'Magnesium'.

Magnesium is found to be 8th most ample element in earth`s crust and 9th most ample in the Universe Magnesium is an alkaline metal having atomic no. 12 and oxidation no. +2. The free element is not fond naturally on the earth, and it is highly reactive. Magnesium is light, strong and silvery white material and gives white light when exposed to atmosphere [1].

1.1. Properties of Magnesium:

Magnesium shows great potential to substitute to replace conventional materials. One of the important advantages of magnesium is its density. Magnesium is as good as or even better than aluminium and many commercial steels in terms of strength. Properties of magnesium, aluminium and iron are tabulated in Table1.

Table 1. Properties of Magnesium[2]

Property	Magnesium	Aluminium	Iron
Atomic number	12	13	
Atomic weight	24.32	26.98	26
Crystal structure	HCP	FCC	58.2
Density (20^{0}C)	1.74	2.70	BCC
Elastic modulus (GPa)	45	69	7.86
Melting point 0C	650	660	207
Boiling point 0C	1105	2520	1536
Specific strength (kNm\kg)	35-260	7-200	30-50
Specific stiffness (MNm/kg)	21-29	25-38	28-30
Coefficient of thermal expansion	25.5	23.6	11.7
Tensile strength (MPa)	240	320	350

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1.2. Usage of Magnesium:

Magnesium is considered to be effective choice in aerospace applications, automobiles and defence application. It is used in manufacturing of aircraft and aircraft engine mounts,missiles components, control hinges, fuel tanks, wings with aluminium alloy. In automobile sector mg is used for wheels, housings, transmissions cases, engine blocks, steering wheels, column, seat frames. It is also used in electronic goods laptops, TV, cell phones, etc. Fig 1 shows the supply of Mg.

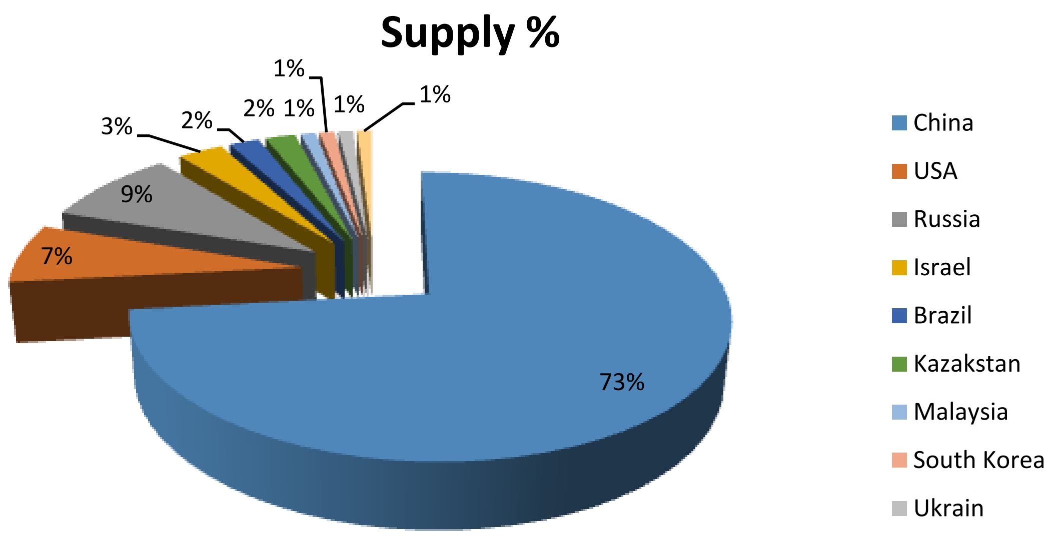

Fig 1. Supply of Magnesium[8].

2. Alloying Magnesium:

The magnesium-alloy development started in the early days of 1945. Research has been conducted on the manufacture of various products by different combinations of alloys and its suitability and association of one element over the other. Magnesium contains hexagonal lattice structure which resist the plastic deformation hence majority of Mg alloys are casted. Wrought alloys came into existence in 2003 [9].

2.1. Alloys for Casting:

For castings AZ91 is the most widely used magnesium alloy. This alloy can be used in both automotive and aerospace applications.It is used specifically for its good casting qualities and generally satisfactory resistance to corrosion. Additionally it is less costly in comparison to other magnesium alloys available in the market. The aluminium in the alloy causes an increase in the tensile strength and hardness of the alloy to a temperature of 120ºC which improves castability. The disadvantages to this alloy are its susceptibility to creep at temperatures above 120ºC and the corrosion resistance is impacted by the presence of cathodic impurities such as iron and nickel.

In order to improve the corrosion resistance higher-purity versions of AZ91 have been formed and have comparable corrosion rates in testing to some aluminium casting alloys. Table 1 shows the properties of Mg alloys with aluminium.

For automotive applications where greater ductility and fracture toughness are required magnesium alloys such as AM60, AM50 and AM20 are used. These are high purity alloys with reduced aluminium contents and are used in the given automotive applications: wheels, seat frames and steering wheels.

If silicon is introduced into the Mg-Al alloys, creep properties can be improved. AS21 & AS41 are such alloys used in automotive applications. An application specific to these alloys was the use in the rear engine of the Volkswagen Beetle. These alloys were used to replace the cast iron crank case and transmission housing saving nearly 50Kg in weight. This weight savings was critical for the road stability of the vehicle [4].

Table 2. Properties of AZ91 alloys [4].

Alloy	Ys (MPa) 20°C	Ys (MPa) 180°C	UTS (MPa) 20°C	UTS (MPa) 180°C	Elongation (%) 20°C	Elongation (%) 180°C
Mg-9Al-1Zn (as-cast)	94	72	157	138	4	14
Mg-9Al-1Zn (T6)	150	121	250	212	5	11

2.2. Alloys for Wrought parts:

Due to the hexagonal crystal structure of magnesium it has fewer slip systems than face centred cubic aluminium which restricts its ability to deform; therefore wrought magnesium alloy products are normally carried out by hot working. Additionally extrusion speeds are five to ten times slower than is possible with aluminium alloys. Instead of describing the specific parts in automotive or aerospace application the best way to detail the results of the literature review of magnesium alloys is by describing the wrought product formed.

Sheet and plate alloys are most commonly AZ31 which is the most widely used magnesium alloy for applications at room temperature. Sheets made from AZ31 have been used for prototype testing for automotive sheet panels, but as the cost of these panels is very high they are not seen often in cars; however it could offer unique opportunities in the future [5].

3. Processing Methods:

A wide variety of manufacturing processing methods and technologies have been developed for Mg MMCs (Metal Matrix Composites). Mg MMC is classified into three main groups based on temperature of processing as shown in Fig 2.

(i) Solid State Processing

(ii) Vapour Processing

(iii) Liquid Processing

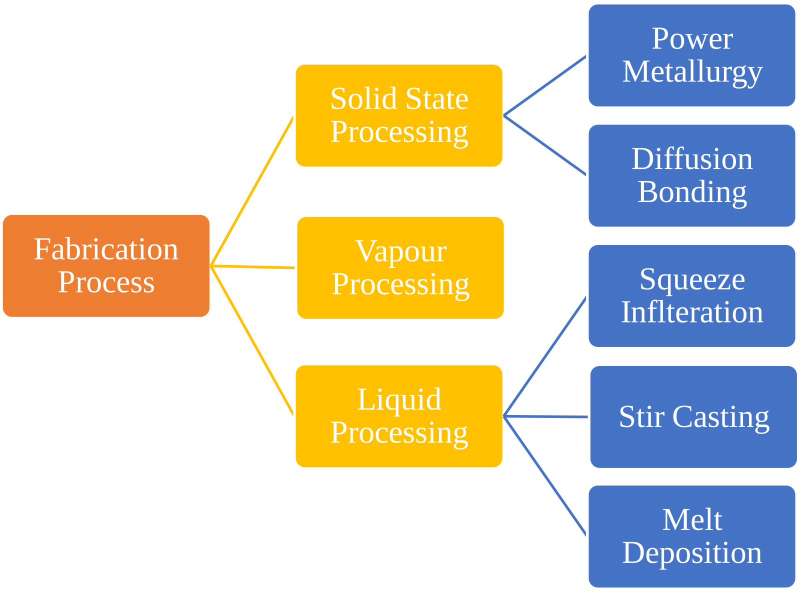

Fig 2. Classification of Magnesium processing methods [2]

A finer grain size increases the strength and the fracture toughness of the material. It provides the potential for superplastic deformation at moderate temperatures and high strain rates. Traditional thermo-mechanical processes generally leads to a grain size above 10µm or, exceptionally, a few microns in diameter. However, several techniques to obtain submicron or Nano -size grains are now available, e.g. vapour deposition, high-energy ball milling, fast solidification and severe plastic deformation (SPD).Recently formulated three requirements to obtain materials with submicron grain size: the fine grained material must have predominantly high angle boundaries, the structure must be uniform over the sample volume and the large plastic strains may not have generated internal damage or cracks. Traditional deformation methods like rolling and wire drawing cannot meet these requirements. Therefore special deformation techniques have been developed. To obtain large plastic deformation is a difficult task since in most metal forming processes it is limited by either material or tool failure.

Various Processing methods for magnesium and its alloys are as follows:

- Equal channel angular pressing
- High pressure torsion
- Reciprocating extrusion-compression
- Repetitive corrugation and straightening

3.1. Equal Channel Angular Pressing:

Equal channel angular pressing (ECAP) was invented Segal in 1977 in Russia. ECAP is based on simple shear taking place in a thin layer at the crossing plane of the equal channels. ECAP has become the most frequently used SPD process. This is due to its low force requirement (small press can be used) and the resulting low tool pressure. He concluded that the strain distribution depended mainly on friction uniformity in the channel sand the details of the channel geometry (sharp vs. round corner). Backpressure appeared to have only small effect in work; he demonstrated advantages of simple shear produced by ECAP over pure shear present in other processes. In order to achieve the required strain in ECAP, the billet is processed repeatedly in the same die. The billet can rotate about its axis between each pass. The four basic options for these rotations are called A, C, BA, and BC, as in Fig. 3. These options have been then classified and assessed in terms of their ability to control the structure and texture of processed materials. From these tests Langdon et al. established that for obtaining homogeneous microstructures of equiaxed grains separated by high angle boundaries the best route is BC. ECAP method does not involve high pressure which is advantageous from the machine and tooling point of view. This may turn into a disadvantage when processing brittle materials. Even ductile materials may require a bit higher pressure to avoid damage accumulation and substantially reduced ductility in further metal forming operations. It is possible to process brittle materials at a smaller pressure provided the temperature high enough [7].

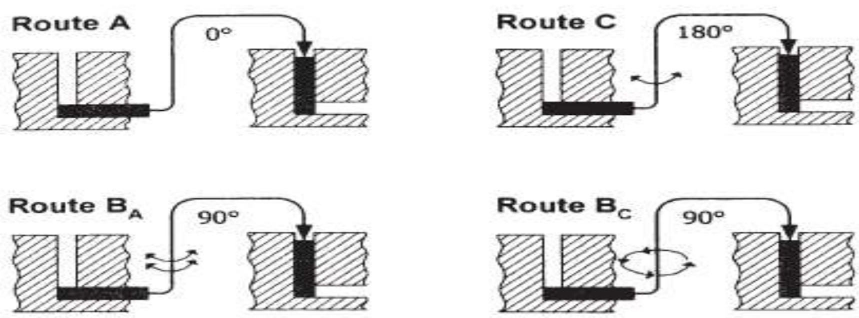

Fig 3. Equal channel angular pressing[7].

3.2. High Pressure torsion:

High pressure torsion was (HPT) first investigated by Bridgman. Bridgman's experiment did not bring much light on the microstructural changes taking place in severely deformed metals. It was Erbel seems to be the first who carried out HPT experiments for copper. He described and interpreted the grain structure evolution towards a structure of dislocation free sub grains with high angles of disorientation and sub micro meter size. He also directed out the increase and eventual saturation of the mechanical properties of severely deformed materials. Numerous papers prove capability of HPT to achieve UFG structure. For this method, a coin-shape sample is pressed between two anvils under hydrostatic pressure (7 GPa). During the build-up of the pressure, the sample is pressed into the cavities in the anvil and a burr is formed at the edge of the sample. Then one anvil is rotated with respect to the other one and the rotation speed can be varied over a large range. This leads to a deformation of the sample by almost simple shear. The burr prevents a contact between the two anvils and upholds the hydrostatic pressure as shown in Fig 4.

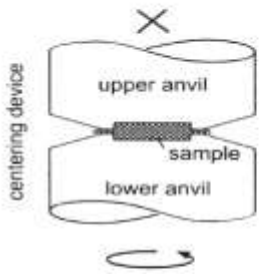

Fig 4. High pressure torsion

3.3. Reciprocating Extrusion Compression:

J. Richert et al. came with the idea of cyclic reciprocating extrusion compression (RE) .RE involves the cyclic flow of metal between the alternating extrusion and compression chambers, Fig 5 The deformation effect could obviously be achieved with the frame/die fixed and the movable punches or vice versa. While the microstructural results of RE have been published widely, the mechanics of the process received less attention. Some results for RE of cylindrical billets are available in where a simplified stress analysis In the stress area, the stress path comprises primary yielding of the material due to extrusion, unloading into the elastic domain and secondary yielding by compression on the opposite side of the yield surface.

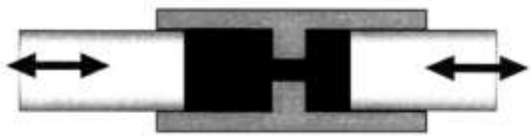

Fig 5. Reciprocating extrusion compression

3.4. Repetitive corrugation and straightening:

Fig.6 shows the groove pressing die for performing the SPD experiment on the AZ31 Mg alloy sheet shear deformation in the material. In this die design, the pitch of the grooves features was 8 mm with an equal horizontal length spacing of 2 mm for the 45° and flat surfaces. During the groove pressing stage, the specimen was placed between a stationary lower and moving upper groove feature dies and allowed to freely deform to the shape of the dies by the movement of the upper die. During the straightening stage, the specimen was placed between two flat surface dies and allowed to deform back to the initial geometry using similar die movement while being constrained in the longitudinal direction by the side walls of the lower die. Fig. 7 shows the illustration of the pressing sequences necessary to achieve one complete cycle with uniform straining of the material. In the groove pressing stage (a–b), the specimen was subjected to a simple shear deformation in the 45° diagonal surfaces between the flat surfaces and has a theoretical effective strain, e_{eff}, of 0.58. The materials along the flat surfaces were not subjected to any straining [3].

Fig 6. Dies for groove press[3]

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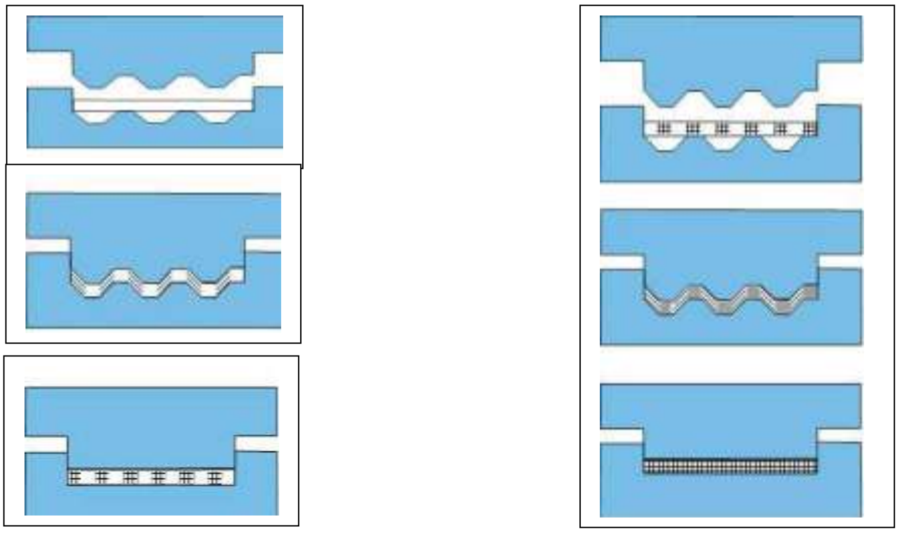

Fig 7. Repetitive Corrugation and straightening[3]

4. Automobile Applications:

Consumer's preference for vehicle performance is increasing day by day. Fuel economy and air pollution are the deciding factors to select the vehicle. In the research aspects these are achieved by using alternate fuels, power train enhancements, aerodynamic modifications and weight reduction methodologies. Among these, weight reduction of a vehicle by alternate materials is the simplest and cost effective solution.

Magnesium is a powerful weight saving option its density is 36% to aluminium, 74% lighter than zinc and 79% lighter than steel. The weight reduction using magnesium when compared with Al/Fe alloys was shown in Fig 8.

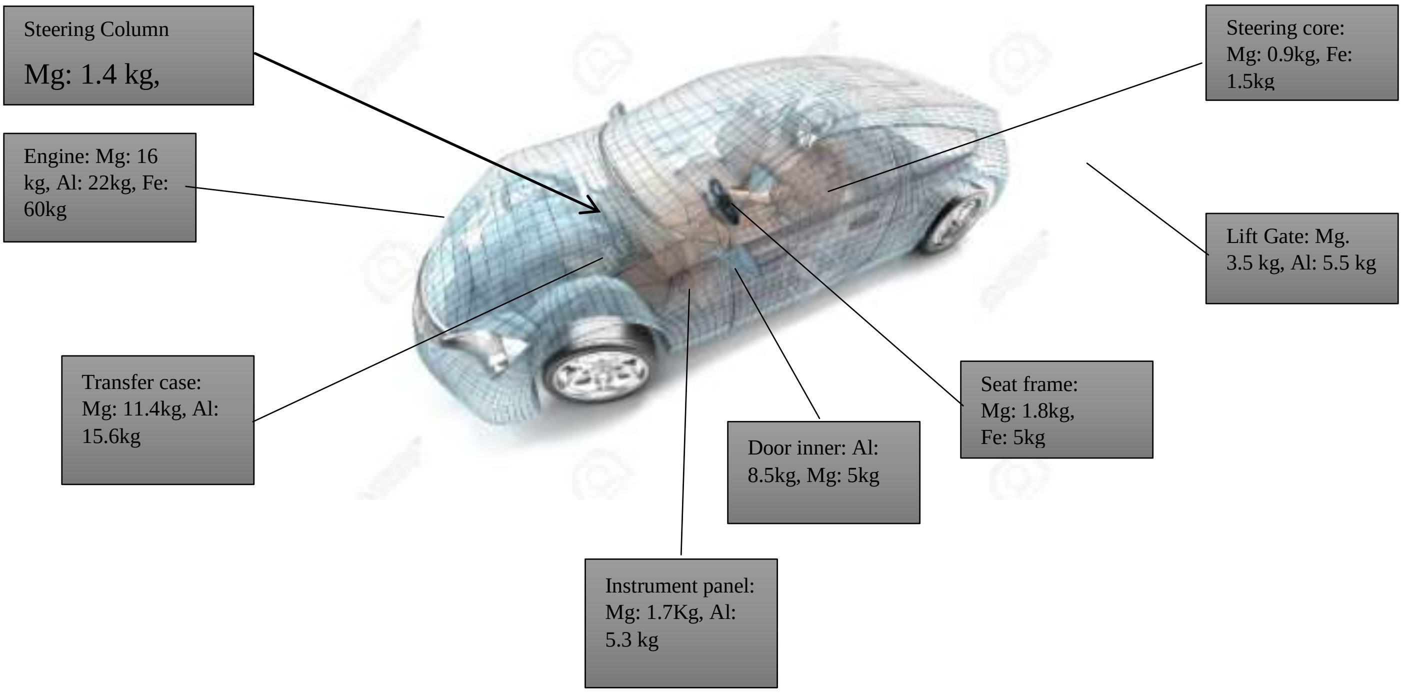

Fig 8 Weight Reduction in bodies[11].

5. Advantages:

- Thin wall: Magnesium alloy part routinely moulded with nominal wall thickness down to 0.020" (0.5mm) providing high strength precise mouldings. Combining the process versatility and tooling capabilities of injection moulding with outstanding material flow. Magnesium alloy opens new intricate, space- efficient design possibilities in many markets.

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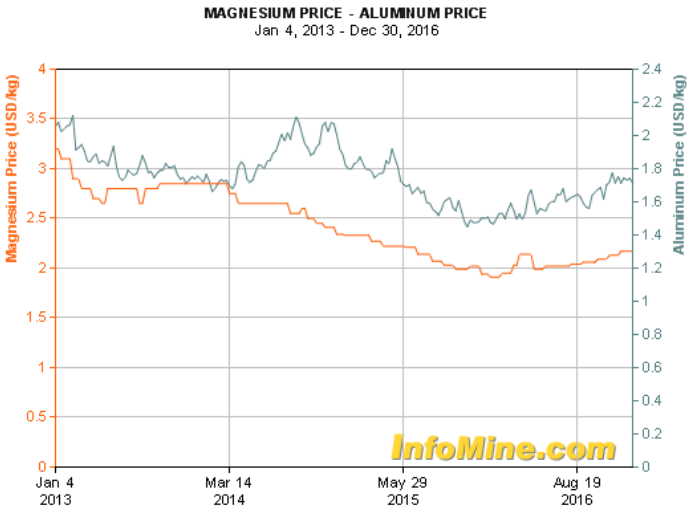
- Light weight: Magnesium alloy components are 34% lighter than aluminium and 76% than steel. With a material density of 0.0065 lb. /in^3(1.81 g/cc). Magnesium alloy compares favourably with most injection moulded thermoplastics and offers a significant increase in mechanical properties.
- High strength: Magnesium alloy have high stiffness, strength, and durability. Which is 20 times more than other material, it have high strength to weight ratio.
- High vibration absorption: Magnesium alloy absorb the large amount of vibration. Hence it increases the comfort level of vehicle.
- Thermal management:Thin wall magnesium alloy components optimize heat transfer with the excellent thermal conductivity of magnesium supporting the needs of miniaturization and efficient thermal management.
- Environmentally friendly :All the magnesium alloy components –painted and unpainted are fully recyclable

6. Disadvantages:

- Difficult to deform by cold working.
- Magnesium has high cost.
- High tendency to galvanic corrosion when contact with dissimilar metals or electrolyte.
- High degree of shrinkage on solidification.

7. Cost:

The cost has been decreasing below the cost of the aluminium since 2013 as shown in Graph 1. Magnesium melting cost is 2/3 as compared to aluminium, while considering productivity which cost 25% higher than aluminium for castings, 300- 500% for permanent mould casting and 200% compared to polymer injection moulding.



Graph 1. Cost comparison of Al and Mg[12]

8. Conclusion:

This article overview the properties, Processing methods, advantages and limitations of magnesium alloys along with automotive applications. It has been revealed by the research that the adaption of Mg alloys as substitution to aluminium and iron alloys has more advantages. The cast magnesium alloys usage is good enough with excellent properties while research on the use of wrought magnesium is continuing. Mg-Al-Zn alloys offer both strength and ductility at room temperatureswith greater flexibility in many applications.

Magnesium alloys provides an opportunity to researchers to work in a broad area where there is a lot of scope to do. With the global awareness on environmental protection, magnesium alloys usage in automotive industry has been considerably increased to reduce the CO_2 emissions, and weight reduction of the vehicle thereby increasing the fuel economy. Weight reduction using magnesium invehicles is interesting and proven with good results. However lot of research is needed in Mg processing to be cost effective.

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