Lightweight Design of High-speed Train under the Development of New Materials

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Abstract: With the development of society and economy, the transportation demand of the railway market is constantly improving, as an important part of railway transportation; high-speed train can meet the transportation needs of long distance, large volume and high density. Compared with the automotive and aerospace industries, the development of lightweight materials of high-speed train is relatively rare, but its role cannot be ignored, the lightweight design of high-speed train is an integral part of the research on high-speed train technology at present, it is an important condition for realizing fast, efficient, safe and convenient transportation of high-speed train. With the continuous development of high-speed train technology, high-speed motor train requires more lightweight materials. This paper has carried out some research on the new materials used in high-speed train, in order to provide a certain references for the lightweight design of high-speed train.

1 INTRODUCTION

High-speed train is a kind of train that can continuously run at high speed, its maximum speed is generally above 200km/h. High-speed train belongs to modern high-speed vehicles, which embodies the train's top science and technology; it can greatly improve the train travel speed and improve the train transportation efficiency. High-speed train is fast, comfortable, stable and safe, energy-saving and environmentally friendly, which is very popular among the people, many countries in the world strongly support the use of new high-speed trains to meet the growing travel demand. On October 1, 1964, the world's first high-speed train was opened in Japan, its maximum speed is nearly 440 kilometers, since then, many countries have begun to build high-speed railways, and the speed of trains has continued to increase. High-speed train in China commonly refer to d-series high-speed train that started after the sixth railway speed increase on April 18, 2007, its maximum speed reaches 350 kilometers per hour. For example, the high-speed train that runs from Beijing to Shanghai takes only five hours, the high-speed train is an important means of transporting that connects cities and plays an important role in the economic development of the city.

(Zi Bingtao, Wang Hui, 2014) The weight of a high-speed train can cause line loss, energy consumption, and cause load on the brake system. At present, the speed of high-speed train is generally more than 200 kilometers per hour, and its impact on the track is much larger than that of ordinary trains; in addition to a certain kinetic energy, the train must overcome various frictional forces when moving. When the speed of a high-speed train exceeds 200 kilometers per hour, it requires several times kinetic energy of an ordinary train, and the resistance to be overcome is more than ten times that of a normal train. Since the weight requirement of high-speed train is stricter than that of ordinary trains, it also requires high power and high performance; therefore, high-speed train is equipped with equipment that is not available in ordinary trains, such as streamlined cones and equipment compartments, etc., this will inevitably lead to an increase in weight. Therefore, lightweight design is the key technology of high-speed train, which is related to the success or failure of high-speed train development. This paper focuses on the application of magnesium alloy, a new lightweight material, in the design of high-speed train.

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2 CHARACTERISTICS AND APPLICATION OF MAGNESIUM ALLOY

2.1 Characteristics of Magnesium Alloy

Magnesium alloy has many characteristics: light weight, good rigidity, certain corrosion resistance and dimensional stability, impact resistance, wear resistance, good attenuation and easy recovery; in addition, it has high heat conduction and electric conduction, non-magnetic, good shielding and non-toxic characteristics. Although the proportion of magnesium alloy is heavier than plastic, the strength and elasticity per unit weight are higher than those of plastic, therefore, under the condition of components and parts with the same strength, the components and parts of magnesium alloy can be made thinner and lighter than plastic. In addition, since the specific strength of the magnesium alloy is also higher than that of the aluminum alloy and the iron, the weight of the aluminum or iron component can be reduced without reducing the strength of the component. The relative strength (ratio of strength and mass) of magnesium alloy is the highest. The specific stiffness (ratio of stiffness and mass) is close to that of aluminum alloy and steel; it is much higher than engineering plastics. In the elastic range, when the magnesium alloy is subjected to the impact load, the absorbed energy is larger than aluminum alloy, so the magnesium alloy has good seismic and noise reduction performance. Figure.1 and Figure.2 show the comparison of magnesium alloy with other materials, Table.1 shows the comparison of physical properties of magnesium and aluminum.

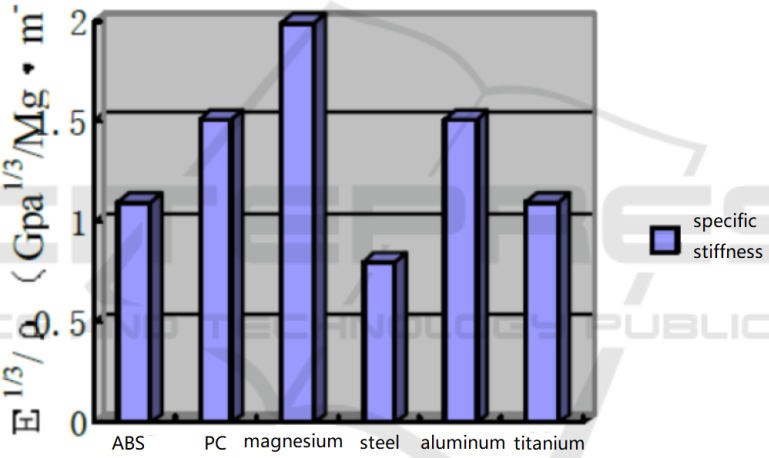

Fig 1. Comparison of specific stiffness between magnesium alloy and other metal materials.

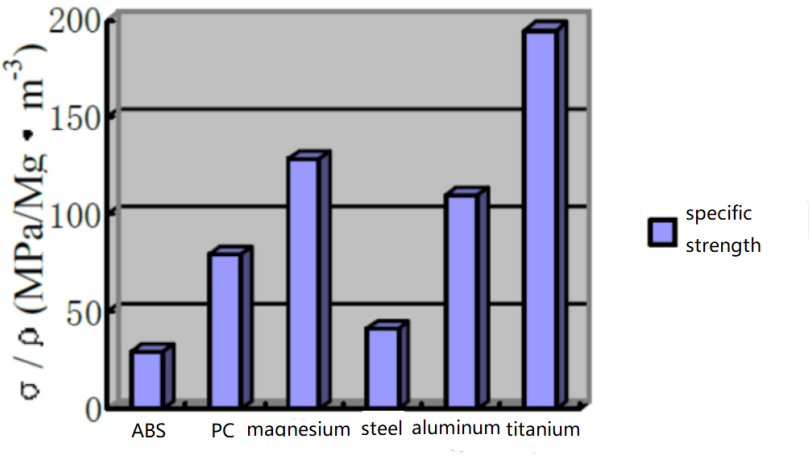

Fig 2. Comparison of specific strength between magnesium alloy and other metal materials.

Table 1. Comparison of physical properties of magnesium and aluminum.

item	magnesium	aluminum
atomic weight	12	13
density 20g/cm3	1.74	2.7
melting point	650	660
specific heat KJ/m3	1.03	0.9
latent heat of melting KJ/kg	368	397
coefficient of heat conductivity W/M.K	154	220
coefficient of thermal expansion×10-6	25.2	23.6

2.2 Application of Magnesium Alloy

(Zhang Kaihan, 2009) Magnesium alloy has low density and it is the lightest metal structural material in practical application, which has the advantages of high specific strength and specific stiffness, good electromagnetic shielding effect, strong seismic shock absorption capability, easy to shape and easy recycling, it has broad application prospects and great application potential in the fields of aviation, aerospace, automotive, 3C products and military industry., which has caused governments, enterprises and research institutions in many countries to attach great importance to magnesium alloy and its forming technology, invested a lot of manpower and financial resources for development research, and achieved certain results. As "green, environmental protection, sustainable" become the main theme of world development, magnesium alloy, which is characterized by light weight and recyclable use, is increasingly becoming ideal materials for modern industrial products, and its market demand has also shown a steady growth trend. The development of modern technology and related industrial technologies, the promotion of magnesium alloy applications in various countries not only eliminates people's doubts about the use of magnesium alloy, but also makes their unique advantages more perfect, the scope of application is rapidly expanding, and make the market development of this emerging material extremely optimistic.

3 APPLICATION RESEARCH OF MAGNESIUM ALLOY IN HIGH-SPEED TRAIN

3.1 Mechanical Properties of Magnesium Alloy

Magnesium alloy is a high-strength metal material; the strength of magnesium alloy is only lower than that of high-strength steel and titanium alloy in metal, which is higher than most engineering plastics. Table.2 is the comparison of mechanical properties between commonly used magnesium

Table 2. Comparison of mechanical properties of commonly used magnesium alloys and aluminum alloys commonly used in trains.

Mg-alloys	AZ31B	H112	160-200	280-320	94	95-97	92	14-21
	AZ80	T5	267	350		72		
	ZK60	T6	305-350	365-410			94	11-15
	Mg-Zn-Y-Zr	T6	321	356			93	7
	AZ91	O	280	331		80		12
	5083	H111	125-200	275-350		90	93	12-15
	5083	0	148	298			100	23.0
	5083	H321	153	305			91	22.5
	6005A	T6	200-225	250-270	75			6-8
	6061	T6	270	290	75	64	84	12
Al -alloys	6082	T6	250-260	290-310	78	67	83	8-10
	6082	T4	149	260			93	18.8
	7005	T6	270-290	340-350		71		8
	7N01	T5	290	345	84		82	
	7018	T79	245	350			95	11
	7020	T6	348	395	77		78	12

alloy and aluminum alloy in trains. Magnesium alloy is a shaped metal; it can withstand a certain degree of deformation at normal temperature before breaking, so that the safety of the equipment can be guaranteed. Table.3 shows the research results of the strain rate affecting the bending strength and the deformation amount. The results show that the magnesium alloy presents a plastic state under high-speed impact. The data in Table.2 and Table.3 shows that the plastically processed magnesium alloy has very strong strength and plasticity.

(Li Wei, et.al, 2016) Note: αW/BMIG--MIG welded joint strength and base material strength ratio, αW/BTIG--TIG welded joint strength and base material strength ratio, αW/BFSW-FSW welded joint strength and base material strength ratio.

Table 3. Effect of strain rate on mechanical properties of (EM Cast) and (Extruded) AZ31.

Strain rate 1/s	EM Cast		Extruded	
	σwb/MPa	Fl/10-3m	σwb/MPa	Fl/10-3m
5.6E-04	321 9.3	9.3	518.3	9.6
2.0E+02	494	6.0	555	4.8

3.2 Welding Properties of Magnesium Alloy

(Zhou Jianle, Wang Jun, 2000) When the magnesium alloy material is applied to a car body structure of a high-speed train, it necessarily involves welding technology. A large number of magnesium alloy welding tests have proved that magnesium alloy have good weldability, and solid state welding methods can achieve better joint performance. Through the successfully developed magnesium alloy ventilating window and magnesium alloy sleeper, it is proved that the equipment manufacturing technology of magnesium alloy has been mature, the welding of the ventilating window frame is completed by TIG method, and the frame of sleeper is welded by cemented composite method.

3.3 Damping and Sound Insulation Performance of Magnesium Alloy

Magnesium alloy has good damping and sound insulation properties. Research on the damping of magnesium alloys has shown that magnesium alloy has excellent properties of high strength and high damping, and they can play a good role in important parts of high-speed train. Magnesium alloy composite structure has better application prospects, such as magnesium alloy composite panel, magnesium alloy honeycomb panel, (Zhi Deyu, 1999) magnesium alloy honeycomb panel has excellent sound insulation performance, it is mainly used for high-speed floor, roof, door and other parts of high-speed train, it has excellent sound insulation performance, the study proves that the strongest noise inside the rail train is around 2000Hz, but the magnesium alloy honeycomb panel still has strong sound insulation ability at this frequency. Table.3 shows the mechanical properties test results of an AZ31B magnesium alloy panel, it can be seen that the ordinary magnesium alloy plate has a normal mechanical performance index not lower than that of the aluminum alloy plate.

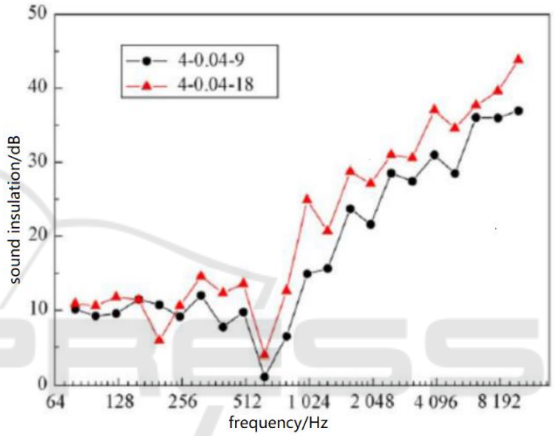

Figure 3. Comparison of sound insulation of honeycomb panels with different heights.

Table 4. Properties of AZ31B wide magnesium alloypanel (thickness is 1.45mm, width is 1450mm, length is greater than 4500mm).

Orientation	Rp0.2/MPa	Rm/MPa	A/%
RD	207	291	21.5
45 °	242	299	24.8
TD	265	310	24.5

3.4 Research on Magnesium Alloy Processing Technology for High-Speed Train

The technology of magnesium alloy is mainly used in the production of various parts in train, which are generally completed by pressure casting, extrusion and rolling, this production technology is now mature. Magnesium alloys used in the manufacture of high-speed train require large-size magnesium

alloy bars and high-efficiency welding techniques and equipment, as well as anti-corrosion technology. Moreover, the reliability study of magnesium alloy is also indispensable. The magnesium alloy processing technology and equipment developed at present are the basis for the manufacture of magnesium alloy high-speed motor trains, based on this, the body of the magnesium alloy high-speed motor car and the manufacturing technology of the whole vehicle will become a reality.

3.5 Benefit Prediction of Magnesium Alloy Material in High-Speed Train Lightweight Design

As a new material for making high-speed train, magnesium alloy has many uncertainties in its application technology; however, with the development manufacturing technology of magnesium alloy material, the application of magnesium alloy in high-speed train will be more and more. By then, the benefits of lightweight design of magnesium alloy materials will be an advantage. The application of magnesium alloy in the automotive industry has produced good energy-saving effects. This is a good example: in the weight of a car, every 100 kg of mass is reduced, gasoline can be reduced by 0.3 L/Km, and CO2 gas emissions can be reduced by 63 g/ Km. This paper predicts the benefits of magnesium alloy materials in the lightweight design of high-speed train. The strength of the magnesium alloy above is similar to that of the existing aluminum alloy used in trains. However, the elastic modulus of the magnesium alloy is 45 GPa, and the elastic modulus of the aluminum alloy is 70 GPa. We must not only ensure the strength but also the rigidity and both are indispensable. The thickness ratio and mass ratio of the two materials can be seen in the following formula:

$$t_{Mg}/t_{Al} = \sqrt[3]{E_{Al}/E_{Mg}}$$

$$m_{Mg}/m_{Al} = (d_{Mg}/d_{Al})\sqrt[3]{E_{Al}/E_{Mg}}$$

E and d represent the elastic and density modulus, respectively, in the formula. In the formula, the thickness ratio is 1.16 and the mass ratio is 0.772. In summary, when the same strength and rigidity are ensured, the weight of the magnesium alloy body is 32.8% lower than that of the aluminum alloy car body. If the weight of the single-section aluminum alloy car body is 10 tons, the weight of the single-section magnesium alloy car body is 6.72 tons. Taking China's CRH3 train eight-car as an example, the aluminum alloy body is about 420 tons, the magnesium alloy body is about 394 tons, and the weight is reduced by 9.38%. In addition, when the running speed of the motor car is relatively low, the energy saving effect brought by weight reduction is more obvious than that of the train at high speed. When the high-speed runs at 200km/H, the energy consumption per unit mileage can be reduced by 9.16%.

5 CONCLUSION

Magnesium alloy material is used in the manufacture of high-speed train, it is necessary to establish a comprehensive and scientific design idea. From the perspective of mechanical properties, processing and casting, resource utilization, manufacturing cost and safety, magnesium alloy has the potential to become new material of high-speed motor train, and it can provide a good foundation for lightweight design of high-speed train.

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