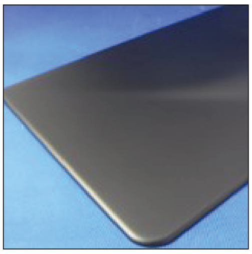

Excellent Thermal Conductive Magnesium Alloy Sheet "SMJ140"

Yuri JONO*, Kazuha SUZAWA, Yu YOSHIDA, and Katsuhito YOSHIDA

Magnesium alloys have the lowest density of all practical metals. Our AZ91 magnesium alloy sheets are used for thin and light laptop computer bodies due to their superior strength and corrosion resistance in addition to their lightweight. In the electronics industry, 5G devices are being implemented to take advantage of IoT or AI, which can cause heat generation in electronic devices. One of the solutions to this is to improve the thermal conductivity and heat dissipation of the device bodies. In this paper, we introduce a new magnesium alloy sheet, SMJ140, having thermal conductivity in a range from 120 to 140 W/(m·K). These values are doubly higher than that of the AZ91 sheet. The heat dissipation of the SMJ140 is similar to that of a commercial aluminum alloy sheet A5052.

Keywords: magnesium alloys, thermal conductivity, weight reduction

1. Introduction

The specific gravity of magnesium (hereinafter "Mg") alloys is 1.8 or less, which is two thirds that of aluminum (hereinafter "Al"), which is known as a lightweight material. Recently, the value of lightweightness has been recognized in the use of Mg alloys for the bodies of thin notebook PCs. The Magnesium Alloy Development Dept. of Sumitomo Electric Industries, Ltd. manufactures AZ91 sheets, which are characterized by lightweightness, high strength, and high corrosion resistance, by applying our unique rapid solidification technology*1 to the generally-used AZ91D Mg alloy*2 and has been promoting practical application for the bodies of thin notebook PCs.

Recently, the COVID-19 pandemic has brought about significant changes in the social environment, leading to a major transformation of personal and social norms and prompting digitization and a shift to online in all activities in society, including personal communication and industrial operations. It is essential to develop the infrastructure to spread the use of IoT and AI technologies, which drive digitization, and the fifth generation mobile communication system (hereinafter "5G"), which accelerates the use of such technologies. Our society, including individuals and industries, is expected to use these technologies to create new value and achieve social innovation.(1) One of the hurdles in achieving such social innovation is the heat generated by electronic devices when developing the infrastructure.(2) The integration of semiconductors used for CPUs, which are important electronic devices and components are getting higher and the heat source has been centralized. The use of IoT and 5G is expected to increase the power consumption and bring about high heat generation at a local part.(2) Recently, the bodies of electronic devices, such as thin notebook PCs and smartphones, have been reduced in volume and size. Due to these factors, heat generation is increasingly expected to exceed the allowable operating range of the electronic devices. Cooling technology for electronic devices will become more important than ever before.(2) One of the methods of reducing the components' temperature is to use materials whose thermal conductivity is high from the viewpoint of the material properties and diffuse heat from the bodies to the surrounding area.(3)

The problem of heat generated by electronic devices may be solved by using high thermal conductivity of Mg alloys, which are well known for being lightweight. This paper reports Sumitomo Electric's efforts to develop Mg alloys with high thermal conductivity and the features of SMJ140, a newly developed next-generation lightweight high thermal conductive Mg alloy sheet material.

2. Efforts to Develop Mg Alloys with High Thermal Conductivity

2-1 Issues in developing alloys

In the development of alloys with high thermal conductivity, it is important to reduce additional elements and produce close-to-pure substances. When we worked on the development of Mg alloys with high thermal conductivity, we considered corrosion resistance in addition to thermal conductivity. This is related to the development history of generally-used Mg alloys, including our AZ91 sheets. Mg is characterized by high ionization tendency and low passivation tendency. Thus, Mg is susceptible to corrosion. Notably, when iron (hereinafter "Fe") of 170 ppm or more is mixed into pure Mg, corrosion resistance is significantly reduced.(4) Fe is present in Mg alloys as an inevitable impurity because ferrosilicon (FeSi) is used as a reducing agent in refinement of Mg and also steel crucibles are usually used to melt Mg alloys and Fe is eluted in molten metals.(5)

To remove Fe, Al and manganese (hereinafter "Mn") are added to generate Al-Mn-Fe compounds and allow them to precipitate at the bottom of crucibles. When Fe is controlled based on the above method, the corrosion resistance is low if the amount of Al is less than 3 wt%. For this reason, many generally-used Mg alloys, such as AZ31B, AM60B, and AZ91D, contain Al of 3 wt% or more. These generally-used Mg alloys whose composition is designed based on such method demonstrate lower thermal conductivity than required for effective heat dissipation. Figure 1 shows the thermal conductivity of pure Mg,[5] generally-used Mg alloys,[5],[6] thermally conductive Mg alloys,[7],[8] Mg-Li alloy sheets, and our AZ91 sheets. Mg-Li alloy sheets are characterized by the lowest density among Mg alloys. They are added for comparison because they are used for the bodies of thin notebook PCs. The thermal conductivity of pure Mg is 155 W/(m·K), whereas the thermal conductivity of many generally-used Mg alloys is less than 100 W/(m·K). The thermal conductivity of our AZ91 sheets is 61 W/(m·K). The marked decrease in thermal conductivity of Mg alloys is caused by the addition of Al. Adding a trace amount of Al significantly lowers the thermal conductivity: 100 W/(m·K) at Mg-1.5 wt%Al.[9] $Mg_{17}Al_{12}$ compound is formed as crystallized products in Mg-Al alloys, but these compounds are easily dissolved into the α-Mg phase at high temperature, and then the amount of Al in the α-Mg phase increases.[9] Efforts have been made to develop thermally conductive Mg alloys whose thermal conductivity exceeds 100 W/(m·K) by reducing the amount of Al added and generating high-melting-point compounds that do not cause Al to be dissolved in the α-Mg phase.[7]-[9]

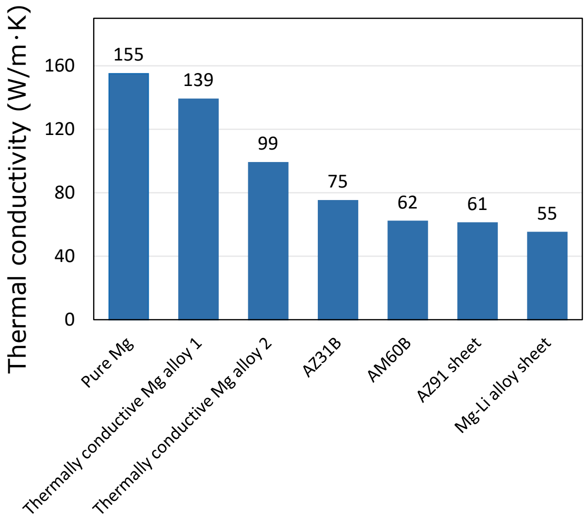

Fig. 1. Thermal conductivity of pure Mg and Mg alloys

2-2 Assumption and concept of alloy development

Sumitomo Electric started its development based on a policy to reduce the amount of Al added because it intended to commercialize pressed products of thermally conductive Mg alloy sheets. However, there was a concern about decreased corrosion resistance because the amount of Al added was less than 3 wt% as discussed above. For this reason, an investigation was conducted on Fe and Al as inevitable impurities in manufacturing before designing alloys for thermally conductive Mg alloys sheets. At Sumitomo Electric, manufacturing process of Mg alloy sheets involves melting of Mg alloys and continuous casting. During the melting process, it was confirmed that Fe was eluted from the steel crucible. It should also be noted that beryllium (hereinafter "Be") is added to prevent combustion of molten metals and as a mother alloy of Al-2.5 wt%Be is used for this purpose Al was found to be mixed in the molten metal. Photo 1 shows the result of a salt spray test on an Mg alloy which contains 139 ppm of Fe and 0.19 wt% of Al. Many white corrosion products were observed on the entire surface. It was found that the corrosion resistance was very poor and that this could be a problem.

Photo 1. Appearance of a Mg alloy, which contains 139 ppm of Fe and 0.19 wt% of Al, after a 98-hour salt spray test

Based on the above, we were able to take full advantage of Sumitomo Electric's rapid solidification technology in the development of thermally conductive Mg alloy sheets. Based on the assumption that Fe and Al are contained as inevitable impurities, we made efforts to design alloy composition that demonstrates corrosion resistance equivalent to commercially available Mg alloys sheets and thermal conductivity of 120 W/(m·K) or more. We succeeded in developing SMJ140, a lightweight Mg alloy sheet material with high thermal conductivity.

3. Features of SMJ140, the Newly Developed Material

3-1 Manufacturing method and properties

SMJ140, the newly developed Mg alloy sheet with high thermal conductivity, is made of alloy that demonstrate thermal conductivity of 123–142 W/(m·K) and good corrosion resistance. The sheets are fabricated by the twin roll casting method, which is one of the rapid solidification technologies. Rolling is performed in the subsequent process to produce thin sheet materials and stamped products, as shown in Photo 2. Table 1 shows the properties of SMJ140 in comparison with those of our AZ91 sheets. The newly developed material is characterized by higher ductility and thermal conductivity and lower density than these of our AZ91 sheets. Its thermal conductivity is double or more that of our AZ91 sheets. This is equivalent to that of A5052, a standard Al alloy sheet material. As explained in the previous chapter, the thermal conductivity of SMJ140 is affected by the Al content, which is one of the inevitable impurities in its manufacture. In the controllable range of Al content, the thermal conductivity of SMJ140 is 123–142 W/(m·K).

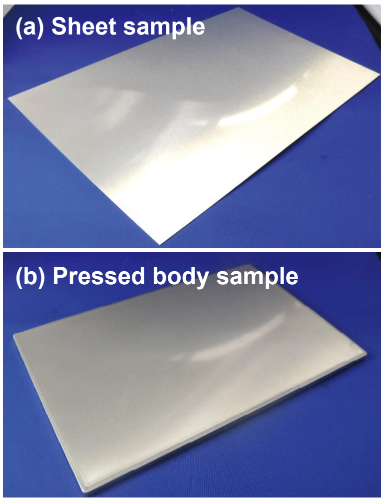

Photo 2. (a) Sheet sample and (b) pressed body sample made of SMJ140

Table 1. Characteristic values of SMJ140 sheet and AZ91 sheet

	Density (g/cm^3)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Young's modulus (GPa)	Thermal conductivity (W/(m·K))
SMJ 140	1.76	255	144	31	45	123~142
AZ91 Sheet	1.81	330	253	8	45	61

3-2 Heat dissipation performance

As shown in Fig. 2, a heat source measuring 50 mm × 50 mm was attached in the center of the sheet material measuring 0.6 mm (sheet thickness) × 300 mm (rolling direction) × 200 mm (transverse direction) using thermal paste (6.5 W/(m·K)) to evaluate the heat dissipation performance by simulating bodies for electronic devices. The heat source temperature and sheet surface temperature were measured under the following conditions: heat source output of 10 W, ambient temperature of 28°C, and natural convection. An infrared thermography camera was used to measure the sheet surface temperature. For specimens, five types of sheet materials were used for comparison: SMJ140, our AZ91 sheets, two types of sheet materials of commercially available Mg alloys (AZ31 sheets and Mg-Li alloy sheets), and A5052. The surface of the sheet materials was coated with a blackbody spray. Measurement was conducted at the constant emissivity of 0.94. The thermal conductivity of respective sheet materials is shown in Table 2. The thermal diffusivity was measured using an AC calorimetric method (ADVANCE RIKO LaserPIT). The thermal conductivity was calculated based on the following formula: thermal diffusivity × specific heat capacity × density. The thermal conductivity was highest in the following order: A5052, SMJ140, competitor's AZ31 sheets, our AZ91 sheets, and competitor's Mg-Li alloy sheets. The change over time of the heat source temperature of the five types of sheet materials is shown in Fig. 3. The heat source temperature increased rapidly from the start of measurement but indicated a constant value after a few minutes (hereinafter "maximum temperature of the heat source"). The maximum temperature of the heat source varied depending on the material. SMJ140 indicated lower values than the AZ91 sheet materials and competitors' sheet materials. SMJ140 was found to be effective in lowering the temperature of the heat source, and the effectiveness was found to be equivalent to that of A5052.

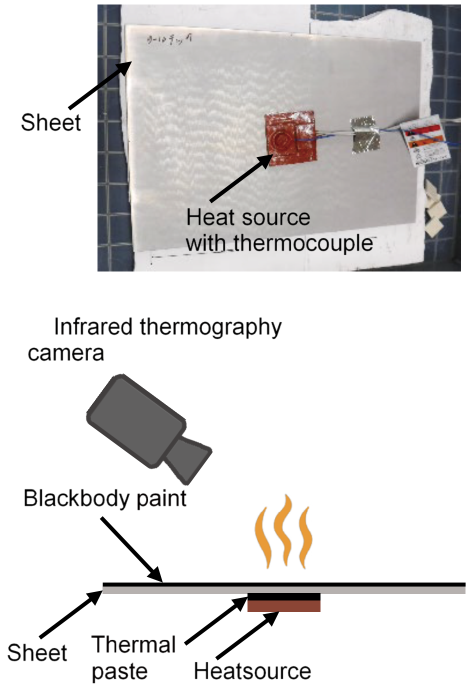

Fig. 2. Schematic diagram of a heat dissipation performance test to simulate a body of electronic devices

Table 2. Thermal conductivities of the specimens used for the heat dissipation test

Samples	Thermal conductivity (W/(m·K))
SMJ140	123
A5052	140
AZ31 Sheet	73
AZ91 Sheet	61
Mg-Li Sheet	55

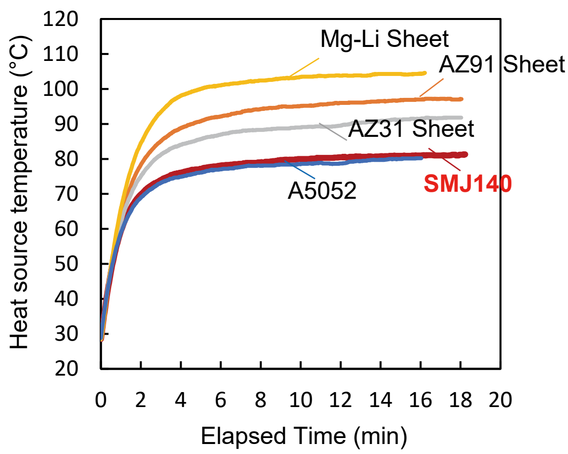

Fig. 3. Increase of heat source temperatures of each sample through time

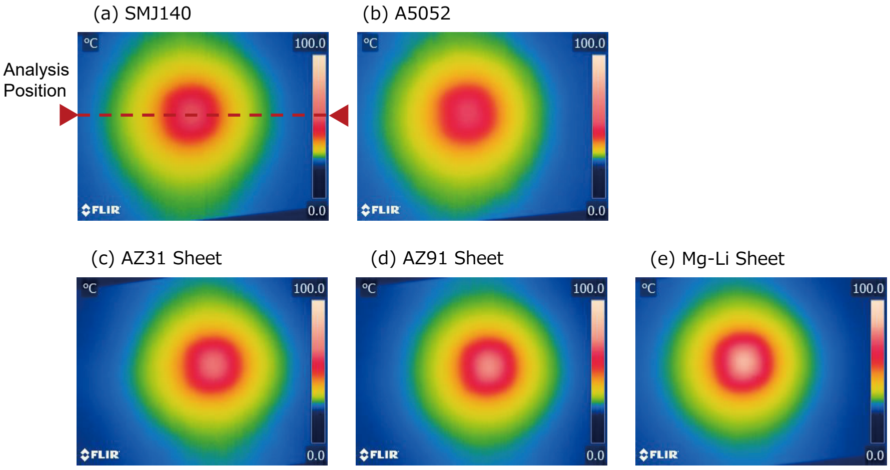

Fig. 4. Temperature distribution of the sheet surface at the maximum temperature of the heat source

Figure 4 shows the temperature distribution on the surface of the five types of sheets when the heat source reached the maximum temperature in Fig. 3. Figure 5 shows the highest temperature, lowest temperature, and difference between the highest and lowest temperatures at the analysis position indicated by the red line in Fig. 4. Regarding the materials with the highest thermal conductivity, such as SMJ140 and A5052, the highest temperature reached was low, and the difference between the highest and lowest temperatures was small. This shows that these materials demonstrate the heat dissipation effect by diffusing heat all over the sheet. That is, they have the effect of reducing the hot spot right above the heat source. Thus, SMJ140 is expected to be applicable to the bodies of electronic devices as a heat dissipation sheet material.

3-3 Corrosion resistance and coating property

To evaluate corrosion resistance, a 96-hour salt spray test (JIS Z 2371, JIS H 0541: 5%NaCl, 35°C) was conducted on the materials. Four types of specimens were used: SMJ140, our AZ91 sheets, and two types of competitors' sheet materials of commercially available Mg alloys (AZ31 sheets and Mg-Li alloy sheets). The appearance of the respective sheet materials after a salt spray test is shown in Photo 3. Regarding SMJ140, opal-like corrosion products were observed on the surface, but the appearance was equivalent to or superior to that of the competitors' materials. No pitting corrosion was observed. The corrosion products were removed by a chromate solution, and the weight reduction amount of the sheet was measured to calculate the corrosion rate. The result is shown in Fig. 6.

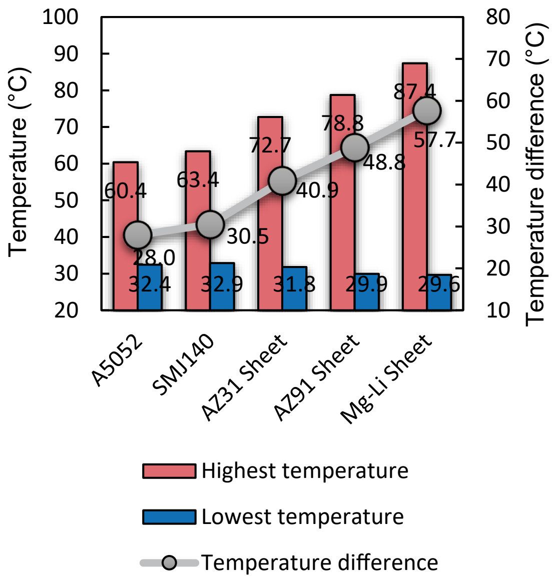

Fig. 5. Temperatures at the analysis position of each sample sheet

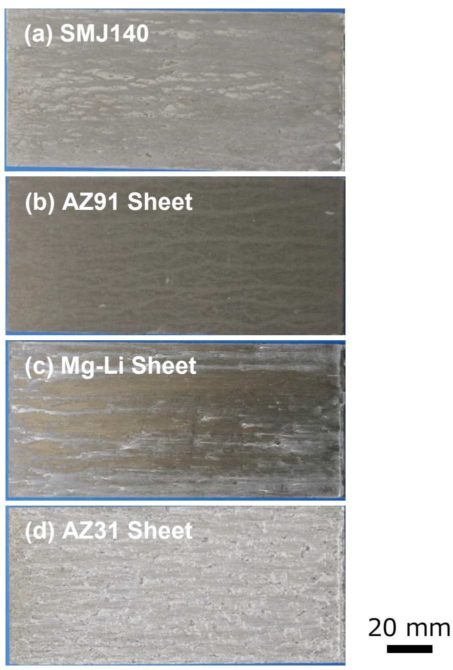

Photo 3. Appearance of the sheets after a 96-hour salt spray test

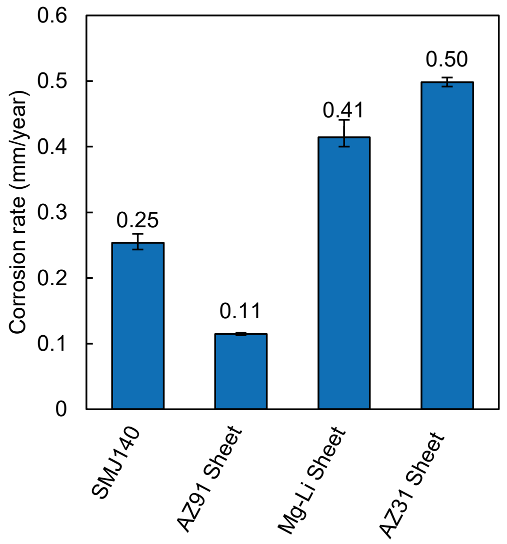

Fig. 6. Corrosion rates of SMJ140, AZ91 sheet, Mg-Li sheet, and AZ31 sheet after a 96-hour salt spray test

SMJ140 demonstrated corrosion resistance comparable to that of competitors' sheet materials. The corrosion rate is only about twice that of our AZ91 sheets. To evaluate the coating property, spraying and electrodeposition coating similar to those for our AZ91 sheets were applied on SMJ140. Photo 4 shows the appearance of pressed products with spray coating (two coats and two bakes using a primer and acrylic resin paint). In terms of appearance, it was possible to apply spray coating equivalent to that of AZ91. It was also possible to apply electrodeposition coating. To confirm the corrosion resistance based on a 96-hour salt spray test as well as coating adhesion of the coating material on SMJ140, the secondary adhesion after a 72-hour heat cycle test, hot water immersion test, and artificial perspiration test (JIS L 0848: acid liquids, alkaline liquids) was evaluated by a cross-cut test (JIS K 5600-5-6). The appearance of a cross-cut sample after an acid artificial perspiration test is shown in Photo 5. This is one of the test results. There is no delamination. The results were good in all the tests. It was found that SMJ140 had sufficient corrosion resistance and coating properties to be used for the bodies of electronic devices.

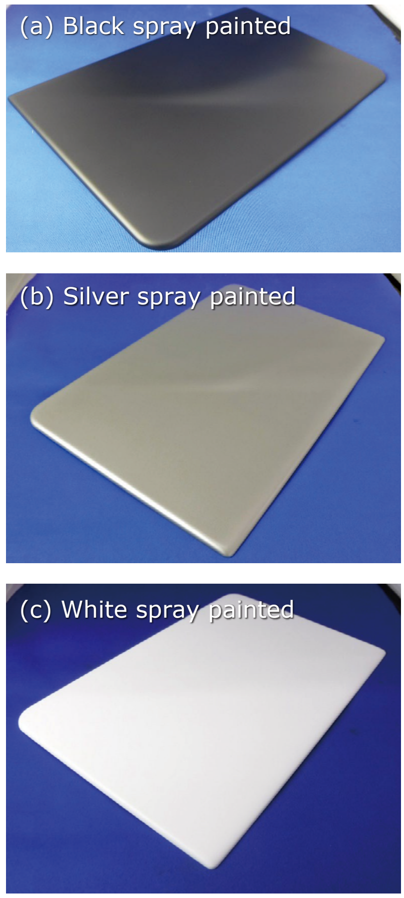

Photo 4. Appearance of pressed bodies spray painted

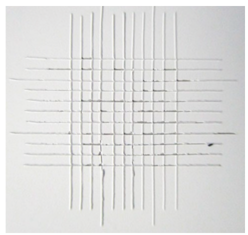

Photo 5. Appearance of a cross-cut sample after an acid artificial perspiration test

4. Conclusion

We have developed SMJ140, an Mg alloy with high thermal conductivity. Its thermal conductivity is higher than those of commercially available Mg alloys. SMJ140 is also characterized by good corrosion resistance and coating properties. The newly developed product is expected to be used as a lightweight heat dissipation sheet material for electronic devices, including bodies for PCs, which must meet the requirements of heat dissipation performance in the future in addition to weight reduction.

5. Acknowledgements

In this development project, we received assistance from President Shigeharu Kamado and Associate Professor Taiki Nakata of Nagaoka University of Technology to evaluate the metallographic structure of SMJ140. We would like to thank them for their help.

Technical Terms

∗1 Rapid solidification: Rapid solidification refers to a process to rapidly cool and solidify molten metals. It improves properties, such as tensile properties, and appearance compared to natural cooling.

∗2 Generally-used Mg alloys: Generally-used Mg alloys refer to Mg alloys that are generally available on the market, such as AZ31B, AM60B, and AZ91D.

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Contributors

The lead author is indicated by an asterisk (∗).

Y. JONO*
• Ph.D.
Assistant Manager, Advanced Materials Laboratories

K. SUZAWA
• Ph.D.
Magnesium Alloy Development Division

Y. YOSHIDA
• Ph.D.
Assistant General Manager, Magnesium Alloy Development Division

K. YOSHIDA
• Ph.D.
Senior Assistant General Manager, Magnesium Alloy Development Division