

Development of a Lightweight Manual Transmission Case of a Heat-Resistant Magnesium Alloy

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ABSTRACT

A manual transmission case was developed by using a heat-resistant magnesium alloy that achieves a 24% weight reduction over a conventional aluminum alloy case. AE62-Ca was developed by improving the castability of the Mg-Al-Ca-RE-base heat-resistant magnesium alloy ACM522, which had a history of use in oil pans, and this new alloy was applied. At the same time, with the objective of achieving a more reasonable price, a recycling process was developed that resulted in a recycling yield on a par with general magnesium alloys. A formed-in place gasket was developed that provided adhesive strength without chemical treatment and fluorocarbon resin coating bolts were also developed to prevent galvanic corrosion at the contact surface.

1. Introduction

In recent years, considering global environmental concerns, vehicle weight reduction in order to improve fuel economy has become a vital issue. One method, adopted particularly in Europe and North America, has been greater application of magnesium alloys.

Honda has used, until recently, general magnesium alloy for engine head covers and steering wheels. In 1999, an oil pan of Mg-Al-Ca-RE heat-resistant magnesium alloy ACM522 went into mass production, but in order to realize even further weight reduction, it is necessary to expand the application of parts using magnesium alloys.

In this project, a heat-resistant magnesium alloy was used for a manual transmission case (referred to as MT case hereafter), subject to the same operating temperatures as the oil pan, achieving a 24% weight reduction over the conventional aluminum alloy case. At the same time, surrounding technologies were also developed to reduce cost.

2. Aims of Development

Figure 1 shows the relationship between engine torque and aluminum alloy MT case weight, for both Honda and other companies. In recent years, as a result of the pursuit of smaller sizes through making the gears and synchros thinner, Honda's case weight is positioned equivalent to other companies or lower. However, the aim of this development project is to secure weight reduction competitiveness through the further application of magnesium alloy.

The authors established the following targets in the development project.

- (1) Giving full consideration to the casting of MT cases with complex shapes, at the same time as developing an alloy that has the same level of strength as the current heat resistant alloy ACM522 and that has more advanced castability, one target is to establish a recycling process that actualizes a return rate equivalent to general magnesium alloy.
- (2) Maintain a level of durability and marketability that is equivalent to those of the aluminum alloy case.

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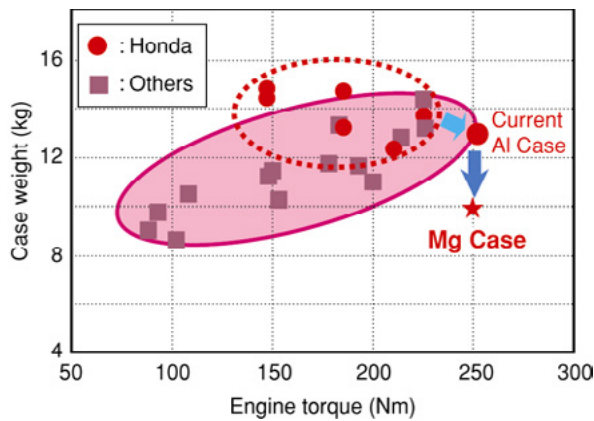


Fig. 1 Relationship between engine torque and manual transmission case weight

- (3) Develop a formed-in-place gasket (FIPG hereafter) that gives adhesion strength equivalent to or better than the aluminum alloy case, without chemical treatment.
- (4) Develop lower-cost galvanic corrosion countermeasure technology.

3. Material Technology

3.1. Development of Heat-Resistant Magnesium Alloy AE62-Ca

3.1.1. Improved castability

Until now, the heat-resistant magnesium alloy ACM522 was developed with the purpose of application to engine parts and was applied to the oil pan. However, in order to apply it to the MT case, which has an extremely complex shape, it was necessary to further improve castability.

The effects of the amounts of Al and Ca, which are the main components of ACM522, were verified by using the hot-cracking test (by ring-die plate) method⁽¹⁾. This test evaluates total length of cracks occurring in a test specimen that was cast using a ceramic shell mold having a specific ring shape.

As given in Fig. 2, the results show that at $1.2 \leq \text{Ca} \leq 1.8$, $5.0 \leq \text{Al} \leq 6.0\%$, it looks like a level equivalent to general alloy AZ91D may be achieved.

However, reducing the amount of Ca causes a drop in creep strength, in comparison with ACM522, and so the amount of rare earth metals (RE) was increased to 2.3% or more.

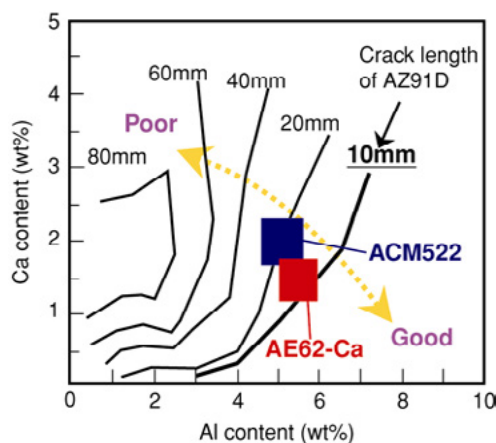


Fig. 2 Effect of Al and Ca content on the total crack length

The results of strength verification of this material, as shown in Fig. 3, confirm that strength equivalent to ACM522 is maintained, and this material was named AE62-Ca.

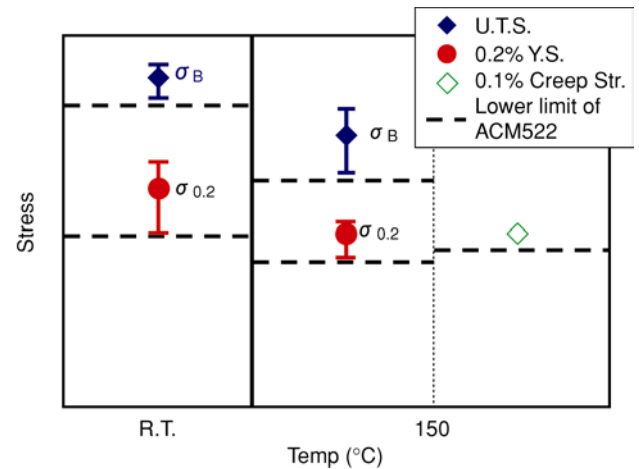


Fig. 3 Strength of AE62-Ca alloy compared with ACM522 alloy

3.1.2. Castability verification with a transmission case

Because magnesium alloy has a lower heat capacity than aluminum alloy, when flow rate drops, fill defects more easily occur. Therefore, with magnesium alloy it is necessary to have casting with high injection speed (high shot speed).

Figure 4 shows the results of verification of the relationship between injection rate, material strength and specific gravity using a metal die.

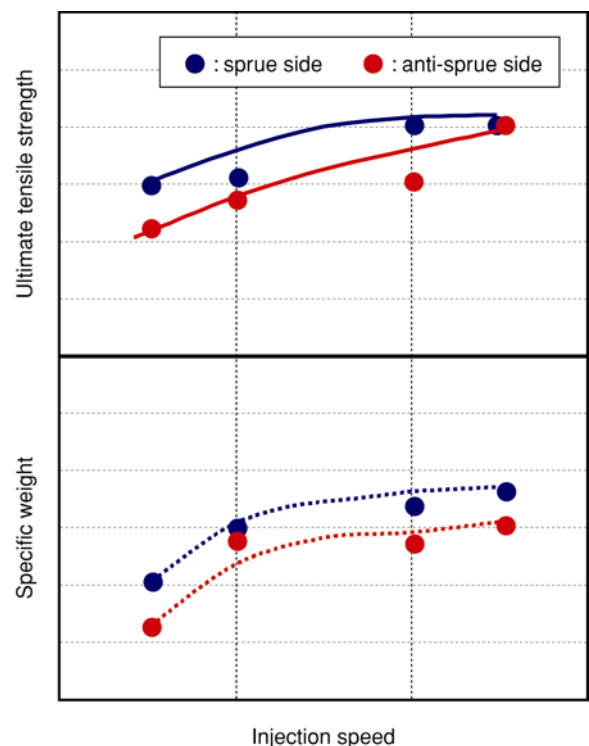


Fig. 4 Effect of injection speed at clutch case

As injection speed drops, there is a noticeable drop in tensile strength and density, and so there is a necessity of maintaining an injection rate at a fixed level or higher.

Implementing further casting simulations, metal die designs were studied. Figure 5 shows an example of analysis using the clutchcase.

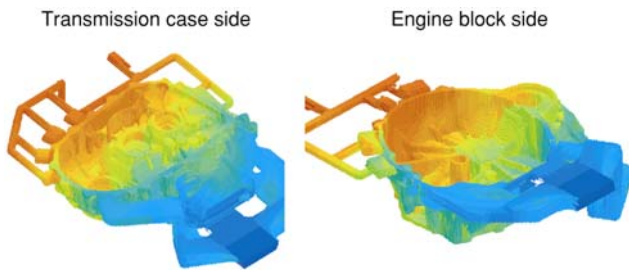


Fig. 5 Flow analysis of molten metal in clutch case mold

Based on the results of these analyses, metal die design was carried out, and the results of continuous casting under uniform conditions confirmed there were good quality parts without cracks.

Figure 6 is a photograph of the outside of a clutch case prototype part.



Fig. 6 Appearance of prototype of magnesium clutch case using AE62-Ca

3.1.3. Recycling process

A recycling process using a Cl flux has been established for general magnesium alloys such as AZ91D, but for the heat-resistant alloy ACM522 the drop in major components such as Ca and RE is large so recycling is not implemented. From the cost reduction point of view, the establishment of a recycling process is also an important issue.

In order to understand the causes, samples were taken of molten metal and sludge (sediment and deposits in the container) at each stage of recycling of heat-resistant magnesium alloy under the same conditions as general magnesium alloy and an elemental analysis was performed.

The results show a drop in alloying in the molten metal during the melting and refining processes. Analysis shows that there are oxides incorporating Ca and RE (rare earth elements) as well as Cl compounds in the sludge. From these facts it is clear that the drop in components is caused by the generation of sludge due to “an oxidation reaction between the molten metal and the air” and “a reaction between molten metal and flux components” during the recycling process. The following two countermeasures were implemented.

- (1) Prevention of air contact on molten metal surface: The covering flux was changed to an SF_6 (6-fluoride ion) gas atmosphere.
- (2) Restrict reaction between molten metal and flux: Change flux introduction and agitation to inert gas bubbling.

The results of carrying out recycling without the use of flux, and through the use of these methods, as shown in Fig. 7, the issue of component part amount drop was resolved.

As shown in Fig. 8, the results of material strength verification show properties equivalent to that of new ingot, and it is possible to use 100% recycled ingot.

In addition, a return rate of 95% was achieved, on a par with general magnesium alloy.

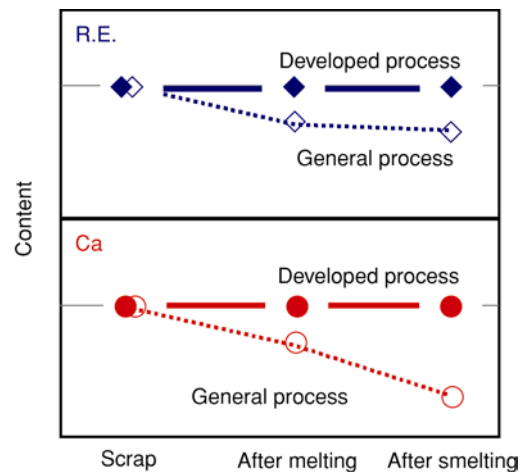


Fig. 7 Loss of R.E./Ca content in recycle process

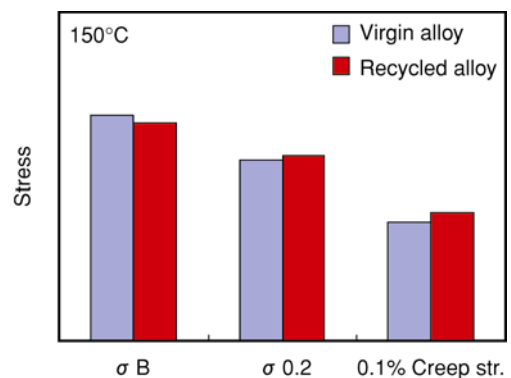


Fig. 8 Strength of recycled AE62-Ca alloy by the developed process compared with virgin alloy

3.2. New FIPG Development

Conventionally, a FIPG has been used to maintain the seal at the contact surface between the transmission case and clutch case. The current FIPG was developed on the assumption of use with aluminum alloy parts, and when used with magnesium alloy parts, there is a drop in adhesion strength. Therefore, with the magnesium alloy oil pan, a chemical membrane was formed with chromic acid treatment to maintain adhesion strength.

Chromate conversion coating increases cost, and because it uses hexavalent chromate, which is a toxic substance, the use of which will be limited in the future, it was vital to develop a new FIPG which does not require a chromate conversion coat.

The drop in adhesion strength with magnesium alloys arises from the fact that there are fewer sites in the magnesium alloy surface compared to the aluminum alloy surface for forming bonds between the OH and silane coupling agent (designated as “AP” agent hereafter), which is the agent supporting adhesion in the FIPG. Figure 9 gives an outline of this.

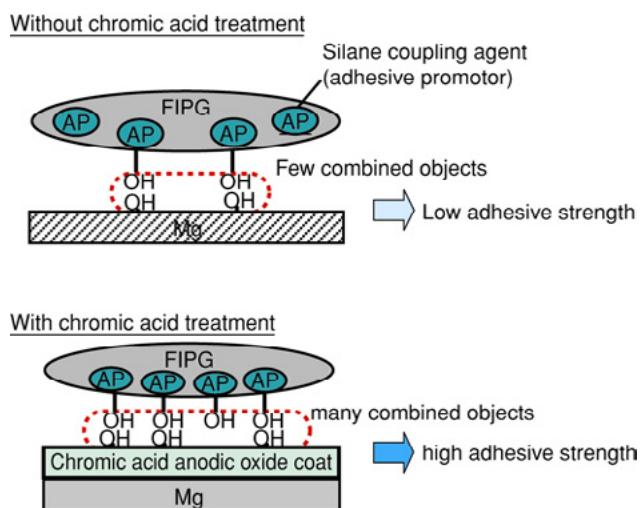


Fig. 9 Adhesive mechanism between FIPG and Mg alloy

The following items were implemented as adhesion strengthening countermeasures, and a performance evaluation was conducted.

- (1) New AP agent used:
Add Alkoxy-silane AP
- (2) Boundary adhesion strength increase:
Lengthen base polymer chain length
- (3) Hardness Increase:
Increase hardening agent amount
- (4) Oil resistance increase:
Add swelling restraint filler

The results are shown in Fig. 10.

Combining magnesium alloy with the current FIPG means a drop in adhesion strength to approximately half that with aluminum alloy. But, with the newly developed FIPG, adhesion strength equivalent to aluminum alloy and the current FIPG is achieved, therefore there is no need for a chromate coating.

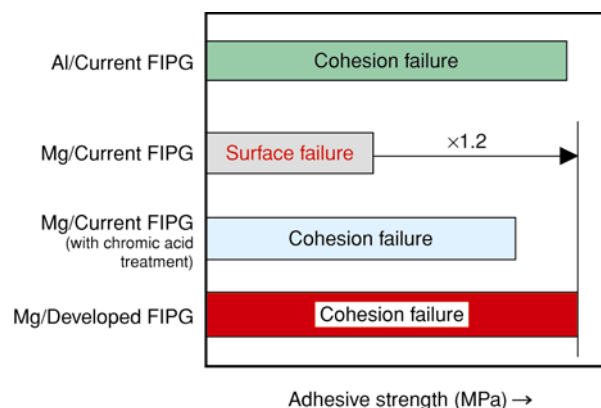


Fig. 10 Comparison of adhesive strength between FIPG and Al/Mg alloy

3.3. Development of Fluorocation Resin Coated Bolt

Because magnesium is the most electronegative structural metal, in comparison with aluminum, when magnesium is exposed to a corrosive environment in a state where there is contact with a dissimilar metal, galvanic corrosion will occur. For parts located under the vehicle body, such as the MT case, water is easily thrown up on it during driving, and particularly in winter, and in regions where de-icing agents are prevalent, there is exposure to an extremely harsh environment, and thorough countermeasures are required.

With the magnesium alloy oil pan, the connection parts were insulated by combining a chrome-plated bolt and an anodized aluminum washer (anodic oxide coating). However, with the MT case, because the number of connection points is quite high, this would mean a large cost increase. Therefore, a new fluorocation resin coating bolt was developed with the aim of reducing cost (Fig. 11).

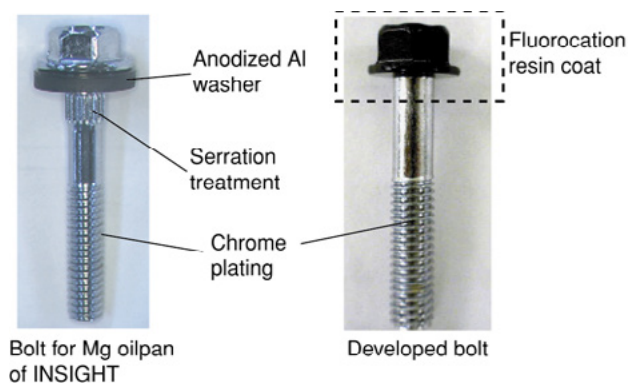


Fig. 11 Galvanic corrosion protection bolt

From the results of the evaluation using the salt spray test, as shown in Fig. 12, it was confirmed that the anti-corrosion performance was at a level equivalent to that of a bolt used with the magnesium oil pan.

In addition, bolt force retention was verified, and it was confirmed that these properties were equivalent to that of existing parts.

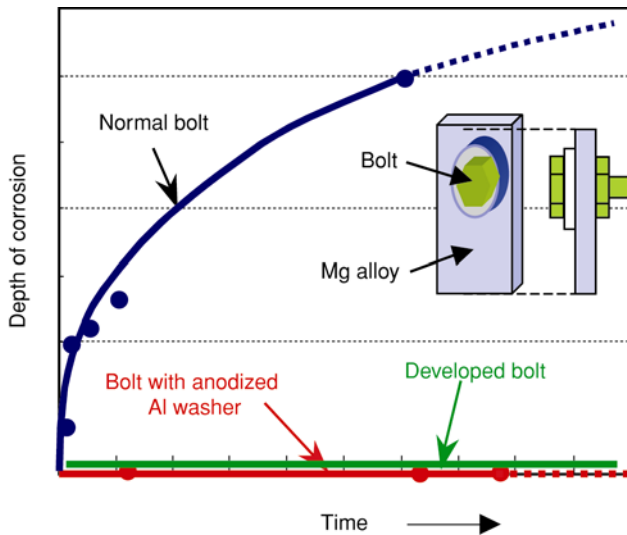
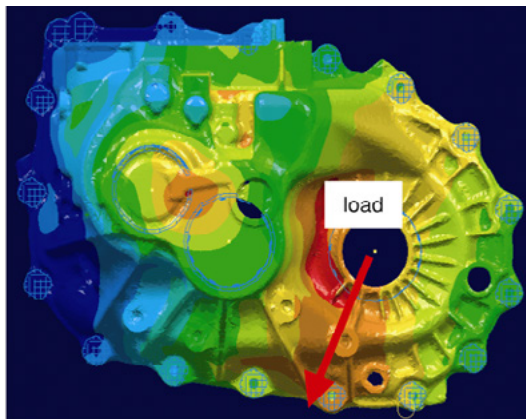


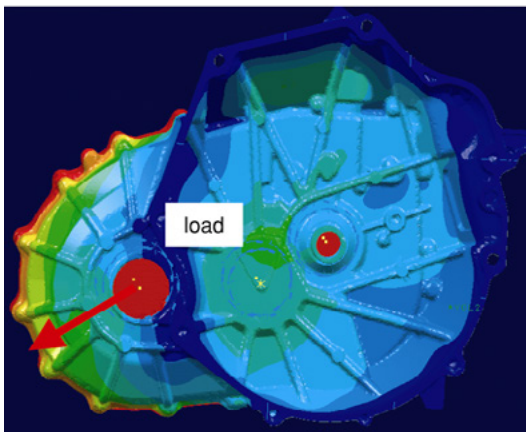
Fig. 12 Performance of anti - galvanic corrosion bolt in salt spray test

4. Design Technology

The Young's Modulus of magnesium alloy is approximately 2/3 that of aluminum alloy, and when the shape is the same, case rigidity is less, seal performance drops, and stress increases, giving rise to the potential issues of insufficient strength and poor NVH properties.



Transmission case side



Clutch case side

Fig. 13 FEM simulation of deformation of MT case

Because of this, when determining the case structure, shape studies were carried out according to

- (1) Analysis of amount of deflection
- (2) Stress analysis
- (3) Power-train rigidity analysis.

The goal was to maintain rigidity equivalent to the aluminum alloy case, with the minimum amount of weight increase.

4.1. Analysis of Amount of Deflection

Figure 13 shows the results of analysis carried out with the same shape as the aluminum case. Because it is clear that there is a large amount of deflection generated in the contact surface around the differential gear due to input from the final driven gear, as a countermeasure ribs were added focusing on the area around the differential gear and radial thickness was increased.

A prototype part was created that incorporated the countermeasure shape, and using the static torsion test, joining behavior in the locations shown in Fig. 14 where measured. As shown in Fig. 15, the results showed a displacement amount equivalent to the aluminum case and an equivalent level of rigidity was maintained.

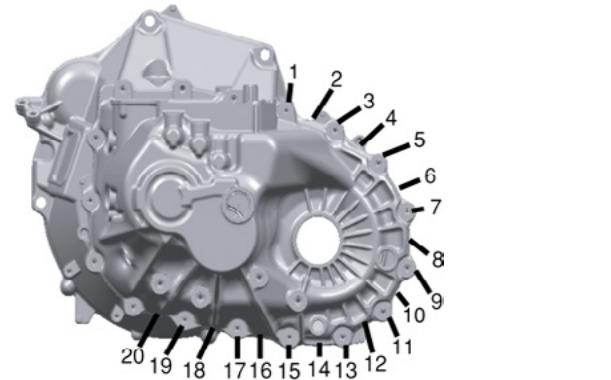


Fig. 14 Measuring points of slip deformation at contact surface between mission case and clutch case

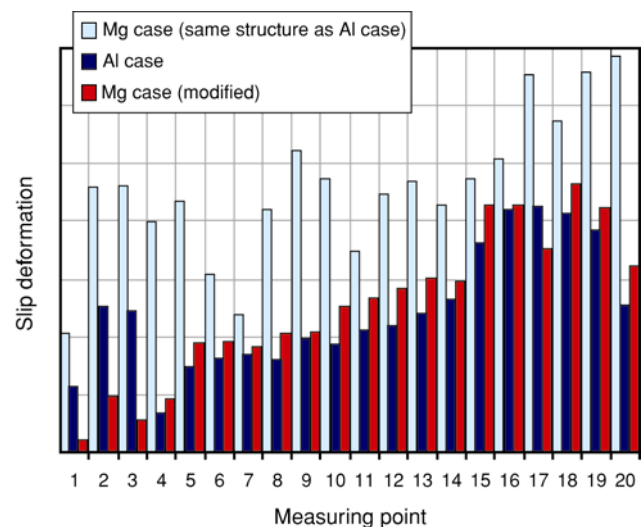


Fig. 15 Comparison of slip deformation at contact surface of case

4.2. Stress Analysis

With the aim of improving the stress analysis simulation of each part, as shown in Fig. 16, analysis was implemented using a model that integrates the transmission case and clutch housing.

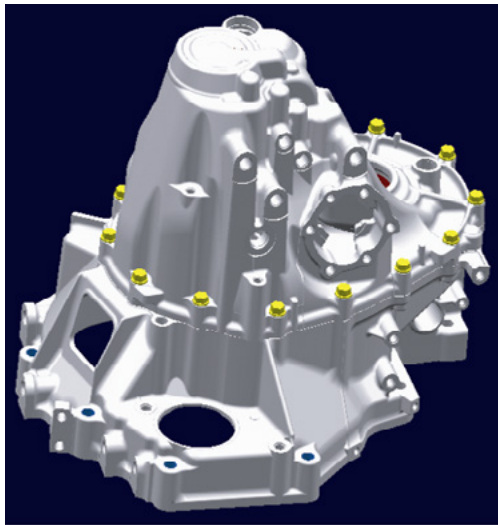


Fig. 16 Image of stress analysis model

Figure 17 shows the results of the analysis. Based on these results, shape countermeasures were applied in areas of high stress, including increasing radii and increasing radial thickness. Therefore, stress levels no more than the target were achieved.

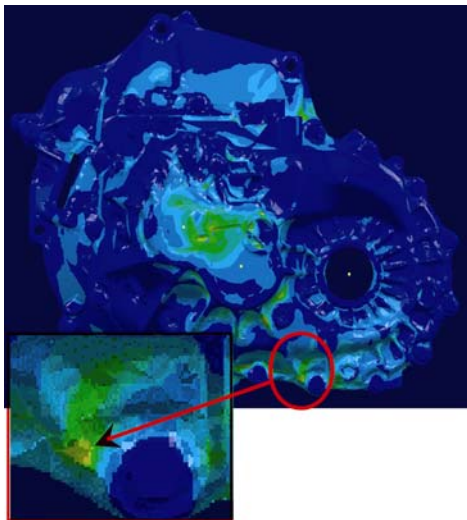


Fig. 17 FEM simulation of stress of MT case

4.3. Power-Train Rigidity Analysis

Because the rigidity of the power train as a whole, when connected to the engine, greatly contributes to NVH properties, further resonance frequency analysis was carried out assuming the engine input state.

Figure 18 gives the results of the analysis in the vertical direction bending mode.

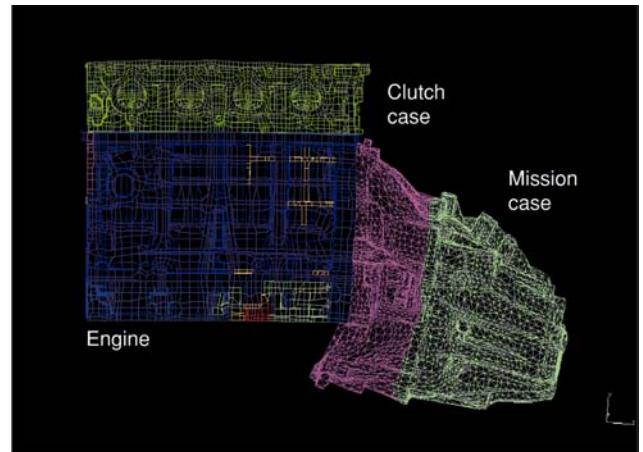


Fig. 18 FEM simulation of resonance frequency analysis at bending mode in the vertical direction

Based on these results, the shape was established so that rigidity would be attained that was equivalent to the aluminum alloy case, focusing on the parts attached to the engine. As shown in Fig. 19 and Fig. 20, NVH performance equivalent to that of the aluminum alloy case was achieved.

In comparison with the aluminum case, the Mg case weight was reduced by 24%.

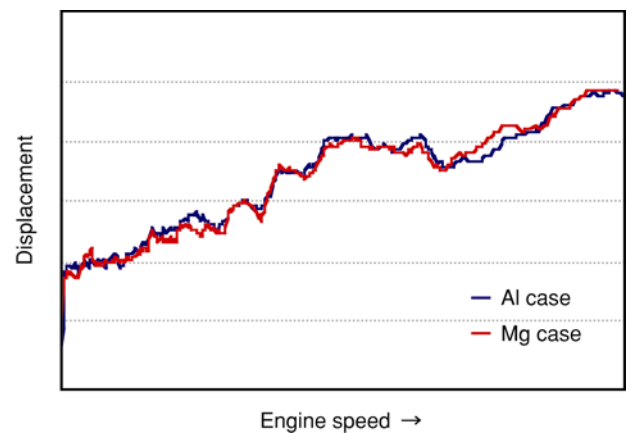


Fig. 19 Displacement of engine rear mount

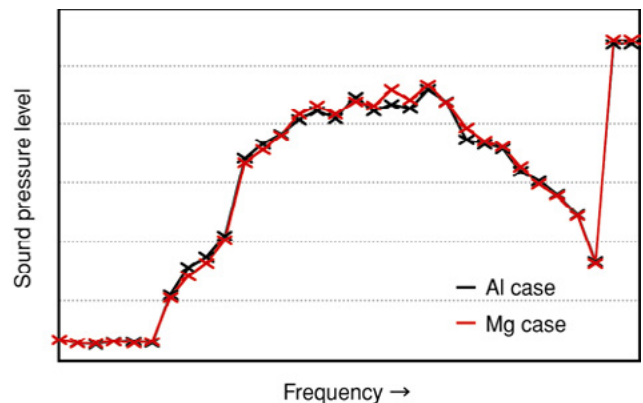


Fig. 20 Sound pressure level from MT case

5. Surrounding Technologies

5.1. Joining Technologies

Generally, when examining bolted joints, it is found that bolt load increases in hot temperatures due to thermal expansion differences between the bolt and the case. This force causes buckling of the flange and threads and creep deformation, which leads to a drop in bolt load. In the case of magnesium alloy, the thermal expansion rate is 20% greater than aluminum alloy, so it is easy for bolt load to drop.

Therefore, for areas where bolt load retention properties are required, such as on the case mating surface, joint specification revisions were made, such as increasing the outer diameter of the bolt flange to reduce stress, and increasing internal thread screw overlap margin.

The results of bolt force behavior at the case contact surface show, as can be seen in Fig. 21, that bolt force is equivalent to that with the aluminum case, or better.

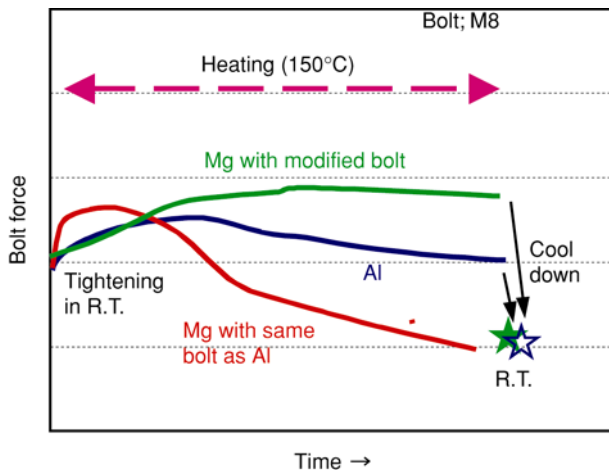


Fig. 21 Comparison of bolt force retention at 150 °C

6. Summary

Using heat-resistant magnesium alloy, a manual transmission case was developed that achieves a 24% weight reduction over the conventional aluminum alloy part.

The technologies used as are listed below.

- (1) Development of the AE62-Ca material, giving improved castability over the heat-resistant magnesium alloy ACM522, and establishment of a recycling process that can achieve a scrap recycling rate of 95%, on a par with general magnesium alloy, with the possibility of using 100% recycled ingots.
- (2) Development of a FIPG that has adhesion strength at least as good as with the aluminum alloy case, without the use of chemical treatments.
- (3) Development of a fluorocarbon resin coating bolt for the prevention of galvanic corrosion of the connection parts.
- (4) Establishment of computer aided engineering to design a magnesium alloy case shape that gives performance equivalent to aluminum alloy parts.

7. Acknowledgements

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References

- (1) Koike, S., et al.: Development of Lightweight Oil Pans Made of a Heat-Resistant Magnesium Alloy, HONDA R&D Technical Review, Vol. 12, No. 1, pp. 167-174 (2000)

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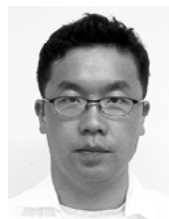
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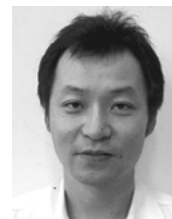
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