NEW TECHNOLOGIES

Weight Reduction Technology for Improved Handling Performance of LANCER EVOLUTION

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Abstract

To be exceptional in all aspects of vehicle dynamics, a high-performance car like the LANCER EVOLUTION must be well balanced in weight, in addition to having excellent powertrain and suspension performances. In order to maximize the effect of weight reduction enhancements on the LANCER EVOLUTION's handling performance, Mitsubishi Motors Corporation considered employing an aluminum material for the roof, the highest part of the vehicle. This paper describes the aluminum roof forming and joining technologies we developed in order to reduce vehicle weight.

Key words: *Aluminum, Weight Reduction, Joining Technology*

1. Introduction

Since its debut in first-generation form in 1992, the LANCER EVOLUTION has been continually evolved and refined through participation in worldwide motorsports competitions (most notably the World Rally Championship). The latest generation, the LANCER EVOLUTION VIII MR, went on sale in February 2004. For this vehicle, an aluminum roof was developed by Mitsubishi Motors Corporation (MMC) as an effective means of cutting weight for superior handling performance. Information on the aluminum roof is presented in this paper. It is noteworthy that the LANCER EVOLUTION VIII MR is the first Japanese production vehicle to have an aluminum roof on a steel body.

2. Targets

A number of automobile manufacturers have developed and produced all-aluminum bodies as a means of weight reduction. However, these bodies have been used with only a limited number of vehicle models for the reason of significant production costs. With the LANCER EVOLUTION, aluminum materials have been used for the hood and fenders because reduction in weight of these parts is effective for improvement of vehicle dynamics and change of their material is relatively easy. With the latest generation, the use of aluminum was extended to the roof in pursuit of even better handling performance.

Since the roof is the highest-positioned part of the vehicle, a weight reduction in the roof effectively lowers the vehicle's center of gravity and can thus greatly improve the vehicle's handling performance. (Calculated with respect to distance from the vehicle's roll axis, the benefit of a weight reduction in the roof is three times as great as a weight reduction in the hood (**Fig. 1)**). However, roof's weight reduction may carry a risk of reduced roof strength and increased cabin noise. The aluminum roof model was developed so as to achieve body strength and cabin quietness comparable with those of the current steel-roof model.

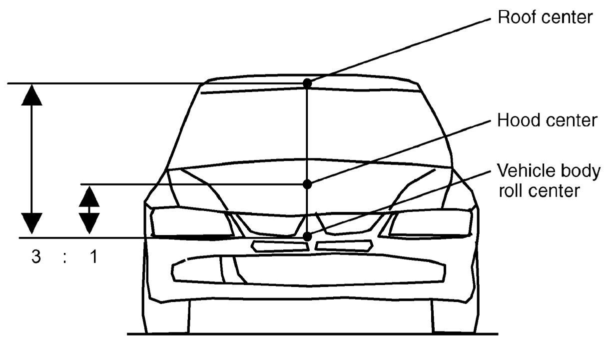

Fig. 1 Effect of aluminum roof

3. Structure of aluminum roof

A 45 % weight reduction in the roof was achieved by the use of the same 6000-series bake-hardened aluminum-alloy sheet (strength-enhanced in a paint oven) that was already used for the outer panel of the hood. The roof panel of the aluminum roof vehicle is fitted with design beads on both sides. The reasons for fit-

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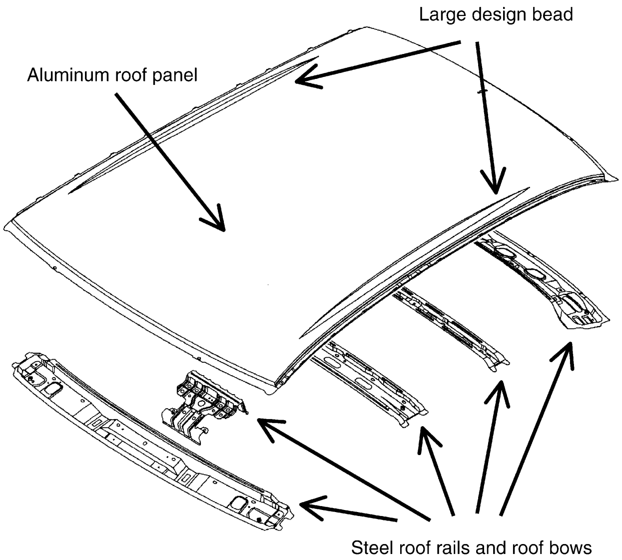


Fig. 2 Structure of aluminum roof

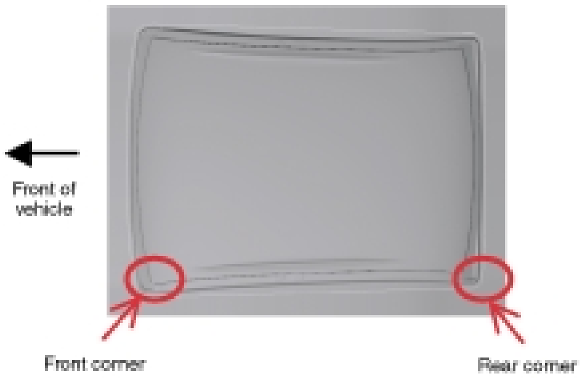


Fig. 3 Model for the forming analysis

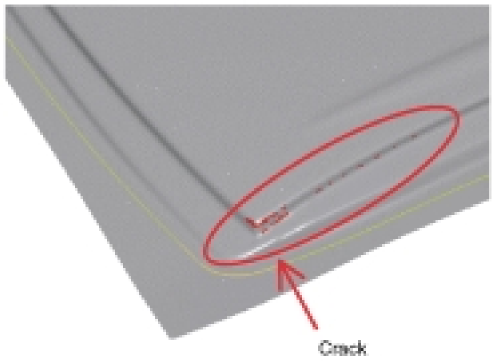


Fig. 4 Crack at front corner shown by roof forming analysis

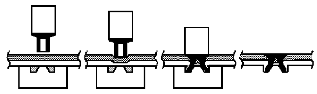
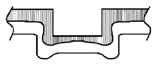
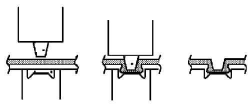
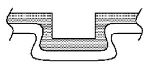
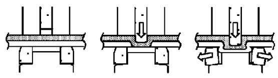
Joining method		Joint sectional	Joining procedure
SPRs			
Mechanical clinch	TOX		
	TOG-L-LOC		

Fig. 5 The way to joining different metals

ting the design beads are to counter heat deformation (discussed in section 4) and to give the aluminum roof a distinctive styling feature (**Fig. 2**).

4. Technological hurdles related to aluminum roof

Many technological hurdles in areas such as joining methods were overcome for adoption of the aluminum roof. An overview is given hereafter.

4.1 Pressing

Aluminum has elongation smaller than steel. Resulting inferiority in the press-formability makes it prone to cracking. Indeed, cracking occurred at the corners of the roof at the beginning of the design study. Computer-aided-engineering analysis using the model shown in **Fig. 3** was performed. As a result, an optimal roof shape that could solve the problem of cracking at corners was successfully determined (**Fig. 4**).

4.2 Joining technology

It was not possible to join the aluminum roof to the steel body by means of resistance spot welding (the joining method generally used to join steel panels to other steel panels). Study was conducted on three different joining methods that could conceivably be used to join the different materials (**Fig. 5**). The results showed that self-piercing rivets (SPRs), which have been successfully used in European vehicles, were the most suitable among these three different methods. An overview is given hereafter.

(1) Static strength

The shear strength and separation strength yielded by the three different joining methods are shown in **Fig. 6**. It can be seen that SPRs are superior to the other usable methods. Although the shear strength and separation strength of SPRs are inferior to those of spot welds, they comfortably satisfy MMC's Spec. This supported that SPRs could be used without problems in this regard.

(2) Fatigue strength

The shear strength and separation strength of an SPR after 10^7 times of stress application are shown in

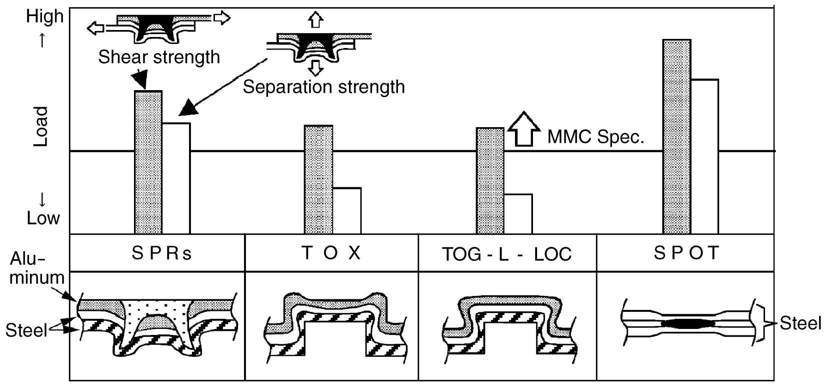


Fig. 6 Static joint strength of joining methods

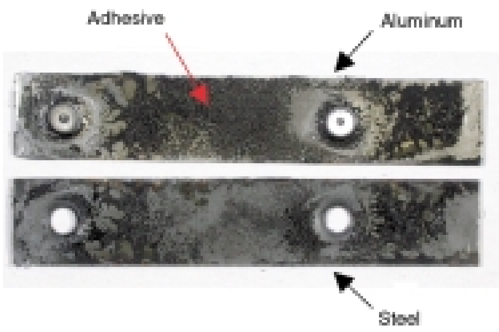


Photo 1 Results of corrosion cycle test

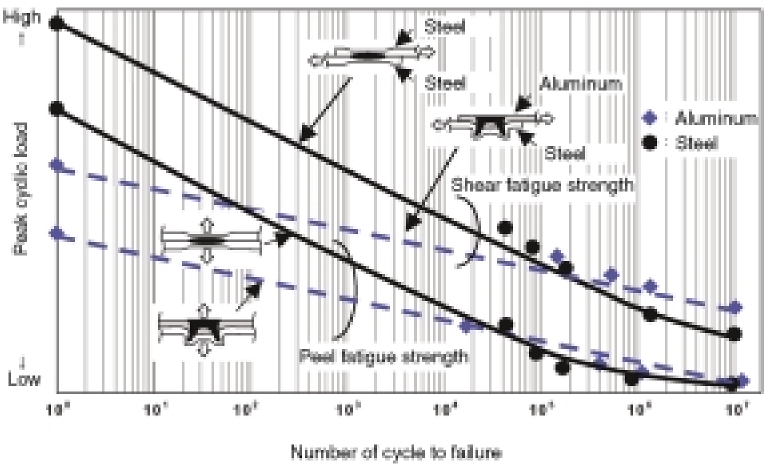


Fig. 7 Fatigue strength of SPR

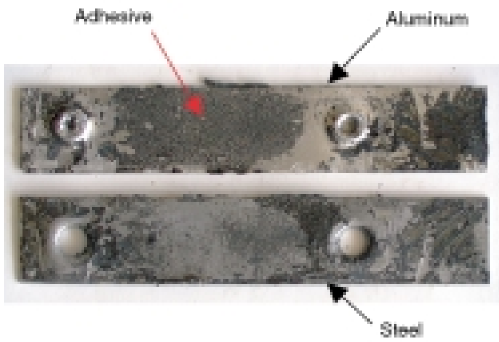


Photo 2 Results of outdoor exposure test

Fig. 7. It can be seen that the shear strength and separation strength at this point are at least equivalent to those of a steel-to-steel spot weld. With a spot weld, the area of the material subjected to heat becomes soft. With an SPR, by contrast, the material in the vicinity of the joint gets work-hardened, meaning that repeated stress does not greatly reduce the fatigue strength of the joint[(1)].

4.3 Measures against electric corrosion

With joints between different metals, the difference between the metals' ionization trends makes electric corrosion a potential problem. For this reason, adhesive was applied to the mating areas of the aluminum and steel to insulate them from each other. The selected adhesive was a structural adhesive that not only offered adequate electric insulation but also was superior in joint strength. Test pieces were made of aluminum and steel joined together with the adhesive; they were subjected to MMC's in-house corrosion cycle test and outdoor exposure test (for 1 year) in Okinawa, Japan. The results are shown in **Photos 1** and **2**. As shown, electric corrosion was not observed. The effectiveness of adhesive application as a means of preventing electric corrosion was thus confirmed.

4.4 Heat deformation of panel

When aluminum and steel, which have different thermal expansion coefficients, have been joined together, the heat used to cure subsequently applied paint can cause heat deformation that is unacceptable by the MMC's quality standard. Large contoured beads were adopted as a means of dealing with this problem.

(1) Heat deformation with pre-existing panel shape

At the beginning of the development program, a prototype aluminum roof was made with the shape used on the LANCER EVOLUTION VII (which was in production at the time) and an inspection for heat deformation was performed when paint had subsequently been applied and heat-treated. It was found that unacceptably significant heat deformation had occurred at each side of the panel.

(2) Action taken to deal with heat deformation

Ways to solve the aforementioned heat deformation problem were considered using the analysis model shown in **Fig. 8**. A design bead shaped to suppress heat deformation (**Fig. 9**) was thus located at each side of the roof and checked for effectiveness on an actual vehicle.

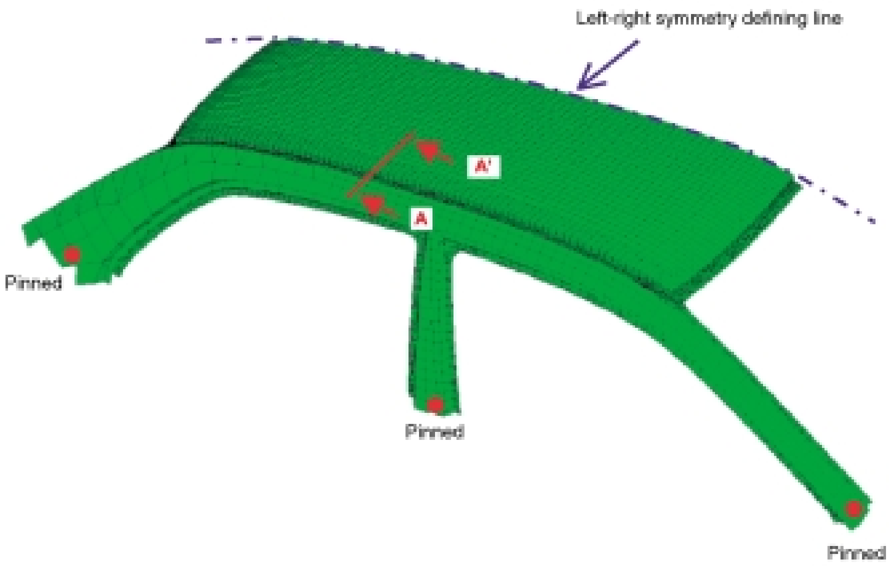


Fig. 8 Analysis model to analyze heat deformation

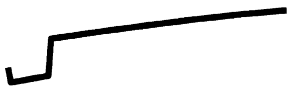
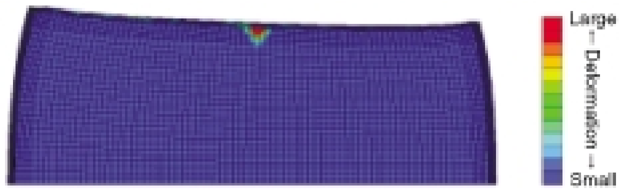
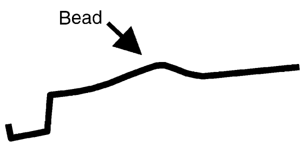
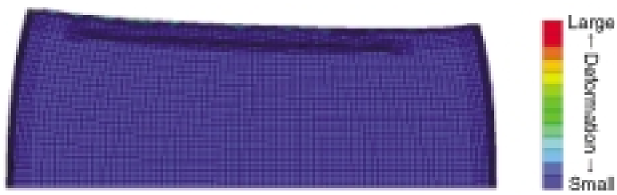
Structure	A - A' section (see Fig. 8.)	Results of analysis
Without bead (conventional structure)		
With bead		

Fig. 9 Effect of bead at edge of the roof

It was found that there was no heat deformation that detracted from external appearance quality of the body.

4.5 Reparability

Since SPRs represent a special joining method and require costly equipment, they cannot readily be used for repairs. Joining methods that allow repairs to be performed less expensively than is possible with SPRs were thus considered. As a result, blind rivets, which offer at least the same strength as SPRs with the joining method used when repairs are performed, were adopted (**Figs. 10** and **11**). Unlike SPRs, blind rivets require holes to be made prior to insertion, meaning that sealant must be used to prevent water ingress.

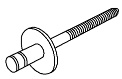
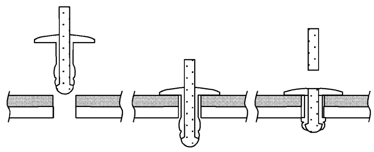
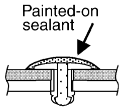
Blind rivets	Joining method	Prevention of water ingress
		

Fig. 10 Blind rivets

5. Results of evaluation with actual vehicle

A vehicle with an aluminum roof was tested. The

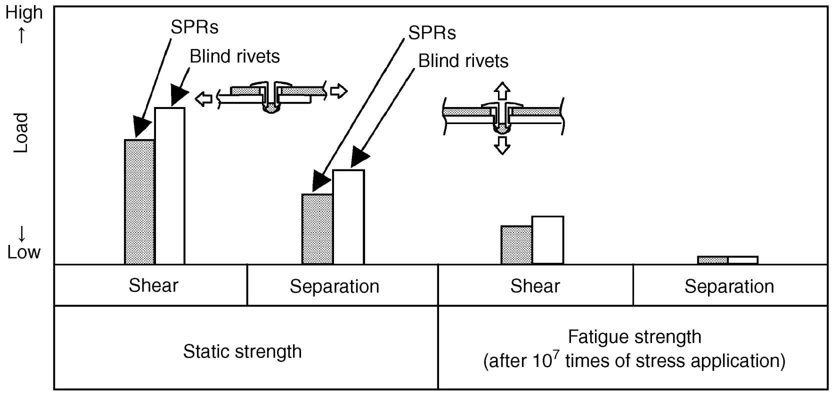


Fig. 11 Static joint strength and fatigue strength of blind rivets

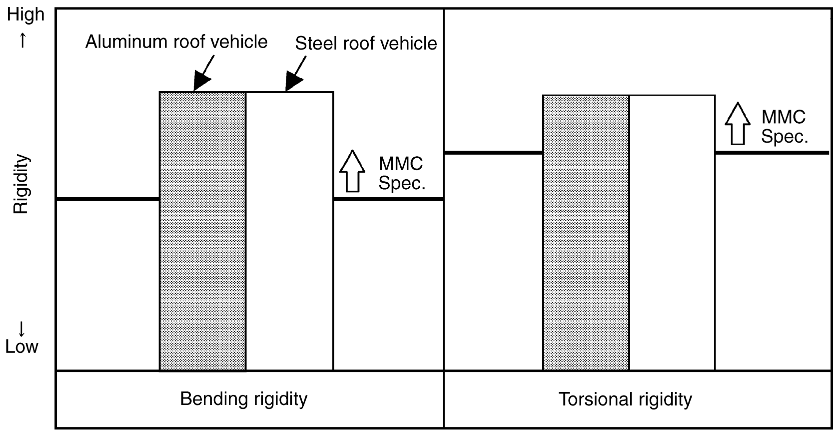


Fig. 12 Static rigidity of body-in-white

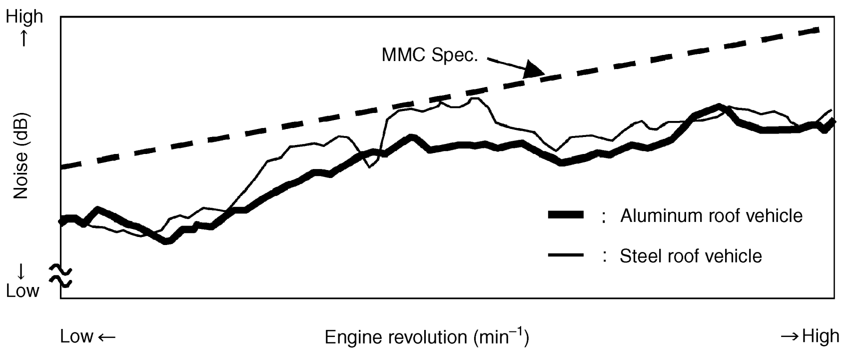


Fig. 13 Noise of front seats center

results are as follows:

(1) Vehicle handling performance

The aluminum roof yielded a 3 mm reduction in the height of the vehicle's center of gravity and a 1.3 % reduction in roll. These benefits are equivalent to those that would be yielded by a 70 mm reduction in the roof height of a vehicle with a steel roof. During steering manoeuvres, they were found to translate into the following handling-stability benefits:

- Roll feel and steering response during steering manoeuvers were improved.
- Vehicle movements when the steering wheel was returned to its original position after steering inputs were smoother, and the vehicle felt nimbler and was concomitantly more enjoyable to drive.

(2) Body strength, durability, and reliability

Body rigidity (bend and torsional) is shown in **Fig. 12**. It can be seen that the body rigidity of the aluminum roof vehicle is approximately the same as that of the conventional steel roof vehicle. Further, MMC's in-house durability and impact tests were performed. The results indicated adequate body strength, durability, and reliability.

(3) Comfort

Oil canning in the roof outer panel and dynamic rigidity in the overall roof were achieved at levels comparable with those of the conventional steel roof. As a result, cabin noise during acceleration (a key index of noise) was found to be low enough to satisfy MMC's standards (**Fig. 13**).

6. Summary

(1) Adoption of an aluminum roof yielded a 45 % weight saving over the conventional steel roof, resulting in handling-stability improvements that cannot be achieved by means of regular suspension and tire tuning.

(2) SPRs were used to attach the roof, and adhesive was used to prevent electric corrosion. These constituted a new method for combining aluminum roof with the vehicle's steel body established successfully.

(3) Positioning a large design bead at each side of the roof was found effective as a means of preventing the difference in thermal expansion coefficient between aluminum and steel from causing unacceptable heat deformation.

(4) A method for using CAE analysis to prevent unacceptable heat deformation was established.

In closing, the development team would like to express its sincere appreciation to Mitsubishi Aluminum Co., Ltd., Kobe Steel, Ltd., Tokai Metallic Manufacturing Co., Ltd., and all other parties inside and outside MMC who co-operated in the development program.

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