Development of the Wiring System Technology to Realize its Weight-Reduction in Vehicles

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ABSTRACT Looking at today's vehicles, the number of system devices equipped in a vehicle, which offer safety, security, and comfort tends to increase. On the other hand, the requirement for reduction in CO_2 emission is growing every year as one of the means to realize the carbon neutral society. Such requirement as to reduce the weight of automotive components is growing further as one of the measures to achieve the reduction in CO_2 emission. Responding to this requirement, we have been promoting the development of the technology to realize not only the weight reduction of automotive wiring systems but also the mass production of its components. In this paper, we are going to report an example of our successful results implemented in a large size SUV launched in the market last year.

1. INTRODUCTION

The requirement for the reduction in CO_2 emission has been growing every year along with the growing awareness in global environmental conservation. On the other hand, the weight of wiring system itself has been increasing caused by the growing number of automotive components required for safety, security, and comfort. Among these components, the weight of a set of Wire Harnesses (W/Hs), one of which is shown in Figure 1, installed all over a vehicle body is as heavy as approximately 50 kg for a large-size SUV to make up approximately 2% of its total weight. Further, the number of its components is as many as approximately 2,000 pieces.

Figure 1 Wire harness (W/H).

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Figure 2 shows the weight percentage of each component group of the W/H. The total weight of wires is more than 50% of that of the whole W/H. This trend has not changed over the past several years.

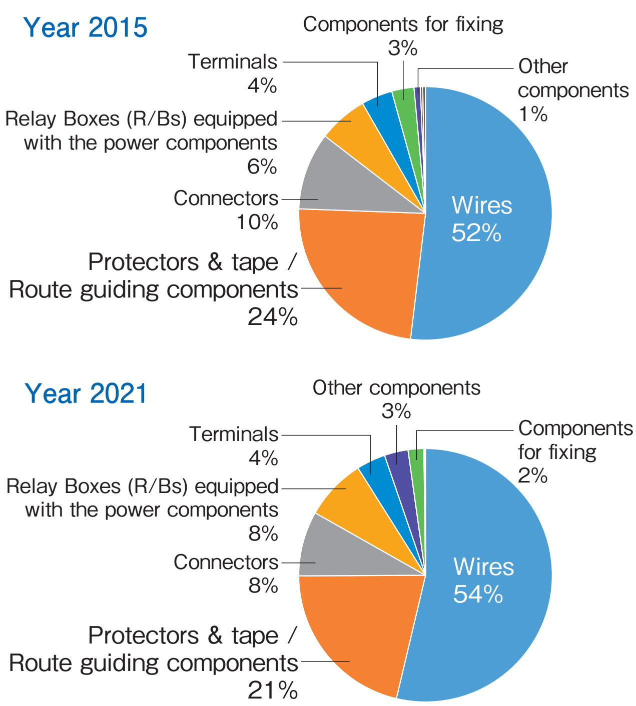

Figure 2 The weight percentage of each component group in the W/H.

It is essential to reduce the weight of wires in order to satisfy the requirement for the weight reduction which has been growing every year and we have to work on reducing the weight of other components of the W/H as well. In this paper, we are going to report an example of our successful results installed in a large-size SUV launched in the market last year.

2. OUR ACTIVITIES TO REDUCE THE WEIGHT OF WIRES

2.1 Our Activities to Adopt Aluminum Wires for W/H

Considering that application of aluminum wires was one of the best ways to reduce the weight of wires which were the heaviest among any components of W/H, we have already been replacing the copper wires with the aluminum ones every year since 2010. Recently, the need for the replacement with the aluminum wires has been growing because the aluminum wires have advantages against copper wires from the aspects of the global depletion of resources and the rising prices as well.

As mentioned above, the application of aluminum wires seems to have a lot of advantages. However, there are big problems to install them in a vehicle. First, the aluminum wire needs larger diameter because its conductivity is lower than that of copper. There is the problem that larger-diameter wires need more space when installing them in the limited small space in a vehicle. Second, the strength of conductor is lower than that of copper. The aluminum wire, especially made of small-diameter conductor is easily broken because of insufficient tensile strength of conductors. Third, a terminal crimped on the end of wire is made of copper alloy. When its contact part with an aluminum wire gets soaked with water, the aluminum is corroded away caused by the bimetallic corrosion. The following shows our technology and its impact on solving those problems mentioned above.

2.1.1 Development of technology for aluminum wires

The first problem of the aluminum wire was that the aluminum conductor larger in its diameter is required when loading the current equivalent to that of a copper wire, because its conductivity is lower than that of copper. As a result, its insulated overall outer diameter becomes larger. We have solved this problem by offsetting the increased size of conductor with a developed thinner insulation to make the insulated overall outer diameter equivalent with that of the insulated copper wire.

We were concerned with the wear resistance of the thinner insulation. But we have satisfied it by applying our PVC composition technology already developed for the thin insulation type wire in which copper wires were already in mass production.

ALVSS 5 and ALVSS 8 were adopted in the large-size SUV launched last year. We had solved the problem of increased wire diameter by making the wire diameter of ALVSS 5 to be equivalent with that of AVS 3 and also ALVSS 8 with AVS 5 respectively by applying the technology mentioned above. (Figure 3)

The second problem of the aluminum wire was the lower strength of conductors. We have solved this problem especially for the small-diameter conductor which required more tensile strength by developing a brand-new aluminum alloy whose strength was equivalent with that of copper, and which had sufficient conductivity to replace copper based on making full use of our metallographic control technology[1]. Applying this aluminum alloy, for example, we have realized a 0.5 mm^2 aluminum wire which has sufficient tensile strength and shock absorption value (toughness) equivalent with those of a 0.35 mm^2 copper wire and good conductivity interchangeable with it as well.

Solving these problems, the wide range of aluminum wires from 0.35 mm^2 to 8.0 mm^2 could be carried in our lineup of products. (Table 1)

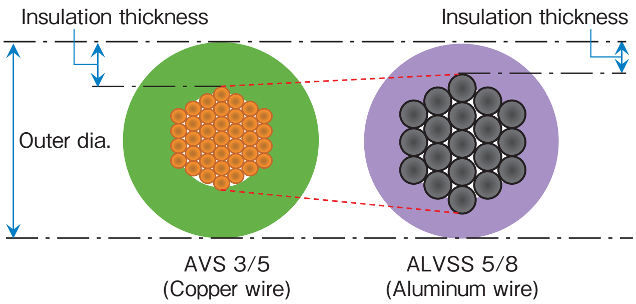

Figure 3 Comparison of AVS 3 / AVS 5 and ALVSS 5 / ALVSS 8.

Table 1 Our product lineup of aluminum wires.

Wire type	Size (mm^2)	Structure of the conductor Number of strands / Strand diameter	Conductor diameter (mm)	Finished outside diameter (mm)	Insulation material (−)	Conductor resistance @20℃ (mΩ/m)	Mass (g/m)
ALVUS	0.35	7/Compressed in circular shape	0.70	1.10	PVC	107.7	1.7
	0.5	7/Compressed in circular shape	0.85	1.25	PVC	77.0	2.3
	0.75	11/Compressed in circular shape	1.00	1.40	PVC	43.4	3.1
	1	16/Compressed in circular shape	1.20	1.60	PVC	32.0	4.0
	1.25	16/Compressed in circular shape	1.40	1.80	PVC	25.3	4.8
	2	17/Compressed in circular shape	1.70	2.20	PVC	16.3	7.5
	2.5	17/Compressed in circular shape	2.00	2.50	PVC	12.0	9.9
ALVSS	2	19/0.36	1.80	2.50	PVC	16.3	8.7
	2.5	19/0.42	2.10	2.80	PVC	12.0	11.2
	5	19/0.56	2.80	3.60	PVC	6.76	18.9
	8	19/0.73	3.65	4.45	PVC	4.08	29.9

2.1.2 Development of the technology for the closed anticorrosion terminal (α Terminal)

The bimetallic corrosion is one of the problems when adopting the aluminum wires in the W/H. It occurs under the environment where all of three factors, water, salt, and oxygen exist. Therefore, such process as to isolate the dissimilar metal interface from these factors, that is, the corrosion protection process is required.

Until now, resin molding was applied as the corrosion protection process to prevent the aluminum conductors from contacting water by covering the whole crimped part with resin. However, this process has not been adopted widely because a terminal with resin molding over the crimped area occupies too much space to fit in the same housing cavity with that for a current terminal with no resin molding process. Furthermore, the individual corrosion protection process required time and equipment and the cost grew much higher.

Therefore, as a method to solve the problems mentioned above at once, we have developed the α terminal which is a closed anticorrosion terminal giving a corrosion protection function by itself without requiring any additional materials or process for corrosion protection. (Figure 4)

The α terminal is such a terminal formed in the process of stamping press and welding to have on one-side an open tube at the wire end instead of the open wire barrel and insulation barrel. When crimping to have electric connection with conductor, the tube-shaped part of the terminal is crimped tightly over the insulation to remove any room against water intrusion. The corrosion protection is realized by preventing water intrusion. Because its structural components are only a terminal and a wire, the expansion of occupying space, which was a problem in case of molding is controlled.

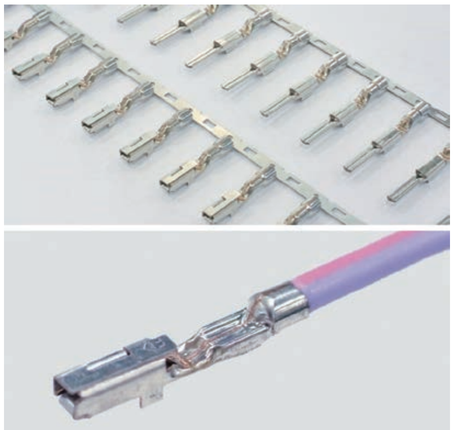

Figure 4 The α terminal.

Furthermore, it is excellent in cost as well, because no additional process or equipment are required as the corrosion resistance process is completed at the same time with the crimping. (Figure 5)

To realize the corrosion-free closed structure of the α terminal, it is required to bond the edges of the tube-shaped barrel of the terminal with a laser welding free from any defects, which is formed in the stamping press. It is important for reducing defects in the welding to minimize the clearance at the edges to be bonded by applying our technology of highly accurate stamping press forming. It is also important to control the effect of springing-back which always occurs at any metal processing. To solve this problem, we have carried out such stamping die design as adopting the springing-go which would generate the process counterforce to the side of squeezed clearance by re-bending it from the excessive bending condition. As a result, we have realized the stamping press process to minimize the clearance between the edges to be welded.

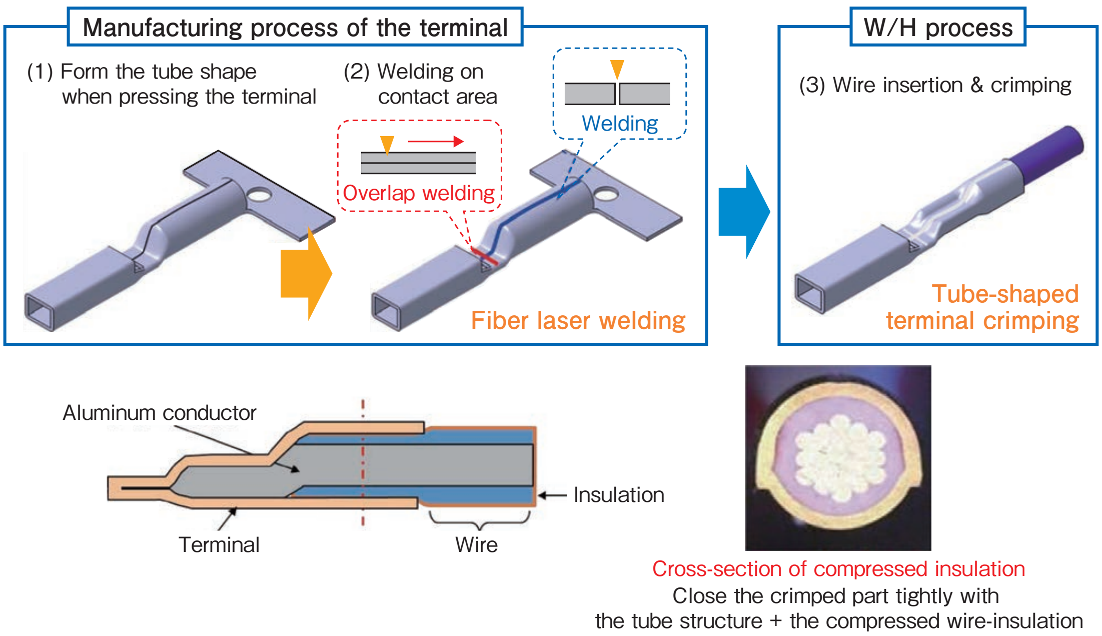

Figure 5 The manufacturing process and structure of the α terminal.

Furthermore, as for the welding, we have developed a combination of the fiber laser and the 3D optical unit exclusively for the manufacturing of the α terminal, which is able to control the 3-dimensional trace of welding to realize the welding speed and the process accuracy to synchronize with the stamping process speed. As a result, we have built our high-speed manufacturing process synchronized with the stamping process. (Figure 6)

Further, it is necessary to prevent the bimetallic corrosion for this joint as well. We have applied the same water protection for the welding joint of copper wires against the corrosion.

We had a problem in the crimping process in which a terminal was connected with a conductor where the crimping form of a current open-barrel type terminal (F-Crimp) could not be applied to the α terminal which was a tube type one. To solve this problem, we have examined crimping forms optimized to combinations of the aluminum wires and the welded-tube type terminals and successfully developed the crimping form in which the tube type barrel with a wire inside was shoved from the top side and the bottom side. (Figure 7)

This shoved shape of the crimp seldom causes the stress relaxation and avoids partial damages to the conductor by the barrel edges to bite through the insulation. It has easily realized both a stable electrical connection and a sufficient mechanical strength to achieve a high reliability in the connection.

As for the corrosion protection process implemented at the same time with the electrical connection, we have analyzed the physical properties of the insulation and its behavior at the crimping process to find the necessary conditions of repulsion force to guarantee the water tightness between the terminal and the insulation. We have established the required specifications for the design to realize these necessary conditions in the crimping process.

Further, we have examined this crimping technology in its implementation in automated equipment to improve the productivity and the quality of the W/H. The first problem found was that it was required to insert a wire very accurately into an uncovered mouth of the tube-type terminal. We have developed both the crimping applicator and the automatic crimping machine combined together and equipped the applicator with both a terminal holding mechanism and a wire guiding mechanism to solve this problem.

The second problem was found that the projected length of conductor after crimping could not be checked by its appearances, and the quality of the crimping could

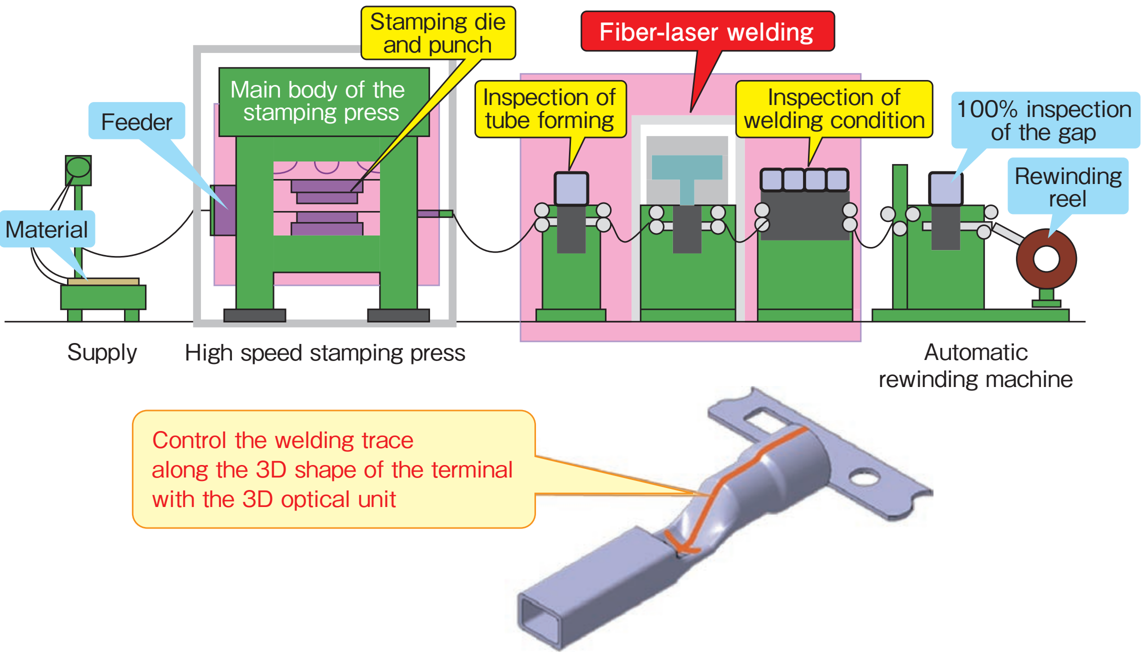

Figure 6 Manufacturing process of the α terminal.

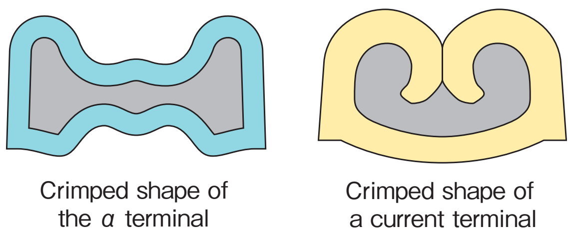

Figure 7 Crimped shape of the α terminal.

not be guaranteed in the process. We put a marking on the insulation for image inspection and linked the wire condition before crimping to the crimped condition after crimping to realize the crimping with high reliability and have solved the second problem.

The α terminal realized by the technologies mentioned above has made it possible to use the aluminum wire under the same environment as the copper wire and has made a great contribution in expanding the adoption of the aluminum wire in the W/H.

Further, we have also been making efforts in developing the larger-size α terminal applicable to the larger aluminum wires of 5 to 8 mm^2 in cross-section. It would realize the replacement of larger-size copper wires, which would produce larger effects in the weight reduction.

We had another problem that it was difficult to weld the thick plate material with high conductivity selected for the terminal by laser, when applying the α terminal to large-size aluminum wires. We had aimed at welding it by a laser with higher output but could not apply it actually, because the unstable melting behavior caused by excessive energy input was too much to control. Then, we applied the beam mode control technology to the conversion of the laser beam into the optional energy profile, which was developed by Furukawa Electric aiming to expand the welding range of the fiber laser. Then, we have established the welding technology to stabilize the melting behavior even under the high output and realized the mass production of the α terminal for a large-size aluminum wire.

2.1.3 Development of welding technology for jointing aluminum wires

With the increasing number of automotive system devices, the number of wires for power, grounding, and signals, which make up these systems, has been also increasing. Along with it, the number of joints which connect these wires together has been increasing as well. There are two techniques to joint circuits, one is to connect wires with a connector, and another is to connect wires directly. From the viewpoint of weight reduction, the welding joint which connects wires directly is more effective for the weight reduction than that with a connector.

In such a situation as mentioned above and aluminum wires are adopted more and more, the development of a new joint technology is required not only to connect aluminum wires themselves but also to connect aluminum wires and copper ones combined together as well.

One of the difficulties to connect different metals of aluminum and copper is difference in their physical properties. We already have two techniques for the joint, crimping and resistance welding. It is difficult to secure the robustness in either the crimping because of their different tensile strength or the resistance welding because of their different thermal conductivity. Considering the difference of physical properties, especially that of melting point between them, we have selected the ultrasonic bonding as our joint technique, which would connect them without melting. During our development, a problem was found that an aluminum wire was bonded to the equipment by frictional heat generated by the ultrasonic vibration. To solve this problem, we carried out the ultrasonic bonding with inserting wires in a copper tube to prevent aluminum from bonding and have solved the problem. With this solution, we have established the joint technology between the aluminum wires and the copper ones, which had never been applied to its mass production. (Figure 8) The bimetallic corrosion protection is required for this joint as well. And the conventional water protection treatment for copper wires welding joint is applied.

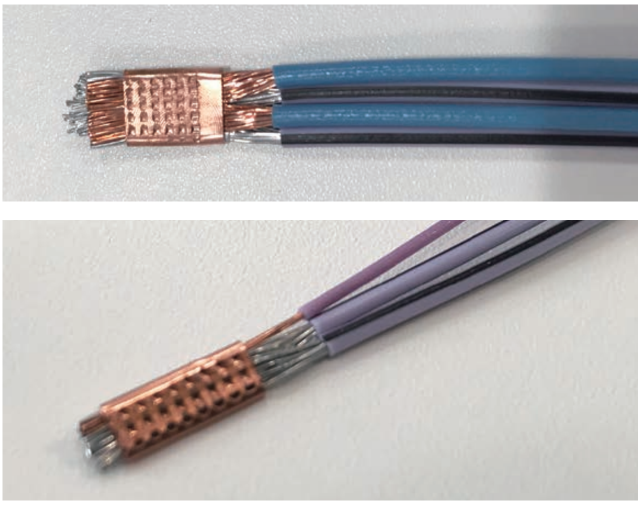

Figure 8 Welding joints between the aluminum wires and the copper ones.

2.2 Development of Technology to Produce the Ultra-thin Copper Wire (0.13 mm^2 wire)

Responding to the requirement for the weight reduction of wires, we have developed such technology as not only replacing copper wires with aluminum ones but also producing ultra-thin copper wires.

There was a problem for the ultra-thin copper wire where the wire itself and the crimped part made up with a thinner conductor had less tensile strength and the wire was easily broken at the crimped part during the pulling operation in the W/H assembling process. This problem was solved by applying a conductor made of harden copper alloy with high tensile strength. With it, we have improved the mechanical resistance against the broken conductors of the wire even for the ultra-thin wire of 0.13 mm^2 and also the crimped part as strong as that of AVSS 0.3.

We have found a further advantage in the ultra-thin wire of 0.13 mm^2. When loaded with the same tensile force, the electrical characteristic of the current AVSS 0.3 deteriorated (increase of electrical resistance of the conductors) a lot but the ultra-thin wire of 0.13 mm^2 had less elongation of the conductors and maintained the electrical characteristics at this condition with less deterioration.

We had to consider the decline in the bending resistance when applying the hard copper alloy and have selected the hard copper alloy with high bending resistance, which was already applied in the robot cable[3], and it has enabled the ultra-thin copper wire to be used at any bending part as well.

The downsizing in diameter of the conductor was carried out for the ultra-thin copper wire of 0.13 mm^2 by compressing its conductor. Furthermore, its insulator could be thinned by using a material with excellent wear resistance. We have realized the further downsizing in diameter with this insulation. (Figure 9)

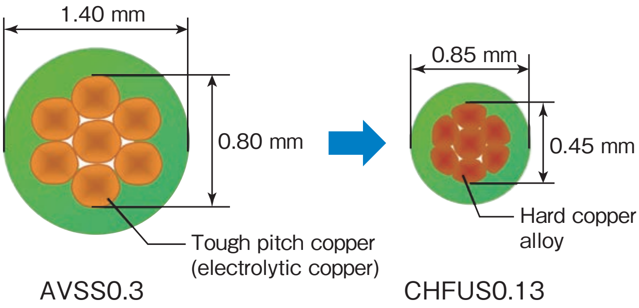

Figure 9 The ultra-thin copper wire of 0.13 mm^2.

3. OUR ACTIVITIES TO REDUCE THE WEIGHT OF COMPONENTS

3.1 Weight Reduction of Exterior Components

As shown in Figure 2, the protectors & tape / route guiding components are the 2nd heaviest next to the wires and the weight of tape with which wires are banded together and a lot of components which are fixed is remarkably heavy. Therefore, we have changed the tape from the normal one with 0.13 mm in thickness to another with 0.07 mm in thickness, and further, we have changed the design to reduce the tape volume by less taping on the areas of protectors where the less taping would not affect any quality issue. As a result, we have realized the weight reduction by approximately 300 g per vehicle.

3.2 The Downsizing and the Weight Reduction of the Power Supply BOX by Integration

Not only the W/H but also the Relay Box (R/B) which carries functions of circuit protection and circuit switching shows a trend of upsizing caused by new automotive functions and equipment added every year.

The targets of our development in this project were those for the large-size SUV. It was equipped with a lot of functions and equipment in it because of its wider diversity in uses. Inevitably, the number of functional components installed in the R/B increased and further, it was designed as capable of installing potential equipment for such as automatic driving and so on for future demand because of its longer model life. So, it has become one of the largest R/B in the world.

In this vehicle, two R/Bs (main R/B and sub R/B) are installed under hood as shown in Figure 10. Comparing the number of functional components installed in these R/Bs with that of the previous model (2015 Model), it increased from 107 pieces to 125 pieces as shown in Figure 11, that is by 16.2% and the total input current increased from 277 A to 371 A, that is by 34%.

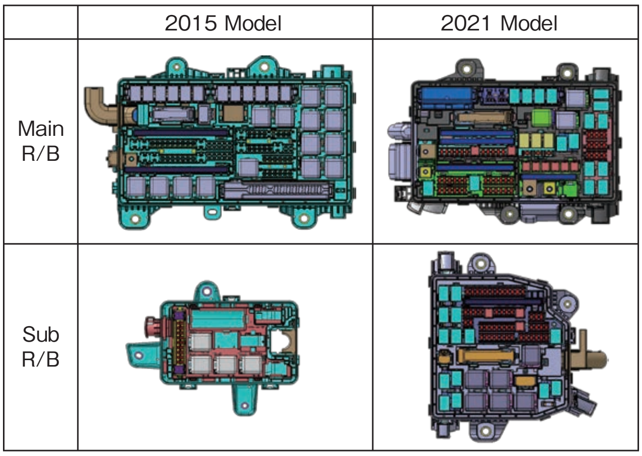

Figure 10 Relay BOX (R/B).

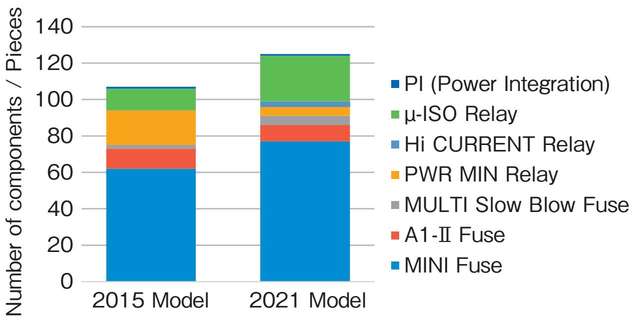

Figure 11 Comparison of the number of components between the new model and the previous model.

These functional components are generating heat and we always have a thermal problem when installing them tightly in the R/B. We have adopted thermal components to suppress the heat generation such as heat pipes and power plates until today, and on the other hand, we have realized the downsizing and the weight reduction of our R/B, by using our thermal simulation technology having been developed in these 20 years.

Regarding the thermal simulation, the amount of heat generation by each component such as a fuse and a relay was calculated, and a heat transfer coefficient was obtained by calculating the amount of heat transferred between the internal and external atmospheres. In addition, loading the heat transfer coefficient actual current value as a condition to the thermal simulation model composed with 3D modeled components, we have carried out the thermal analysis and Joule thermal analysis reflected with self-heat generated from wires and bus bars composing the circuit. And we have got the accuracy within ± 5°C compared with an actual measured data. (Figure 12)

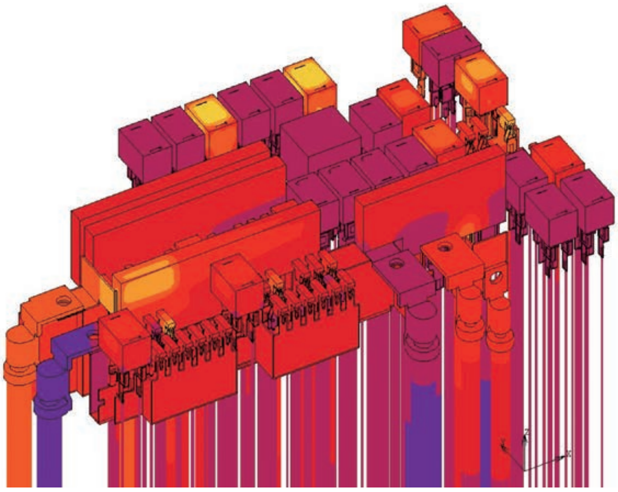

Figure 12 3D contour view of the R/B thermal analysis.

Feeding the result of the simulation mentioned above to our design, we have optimized the arrangement of components in the R/B to uniform the temperature in it. As a result, we have satisfied the specified requirement without adding any thermal components.

Considering the functional difference of components, the new model has accomplished the downsizing (projected area / number of functional components) by 5.3% and the weight reduction (total weight / number of functional components) by 19.5% compared with those of 2015 model.

3.3 The Technology Development of Aluminum Repair Sleeves

In addition to our activities for the weight reduction of components, considering the spread of aluminum wires, we have developed the aluminum repair sleeve as our support to an end user, which is used when repairing a vehicle and contributed to the weight reduction by supporting the spread of aluminum wires.

The current repair sleeve used for copper wires in repairing the W/H is not good enough in securing the electrical performance of aluminum wires to be applied for the W/H which includes aluminum wires. We have developed the repair sleeve applicable for repairing the W/H including aluminum wires to solve the problem mentioned above. (Figure 13)

The structure of the aluminum repair sleeve is adequate for its application to both aluminum wires and copper wires. A ratchet type tool is in use to be sure to make the necessary crimping shape and compression rate. A heat shrink tube containing the adhesive free from any negative effects to the electrical performance is applied for electrical insulation and water protection. With those mentioned above, we have successfully developed the repair sleeve for aluminum wires capable of securing the electrical performance of aluminum wires.

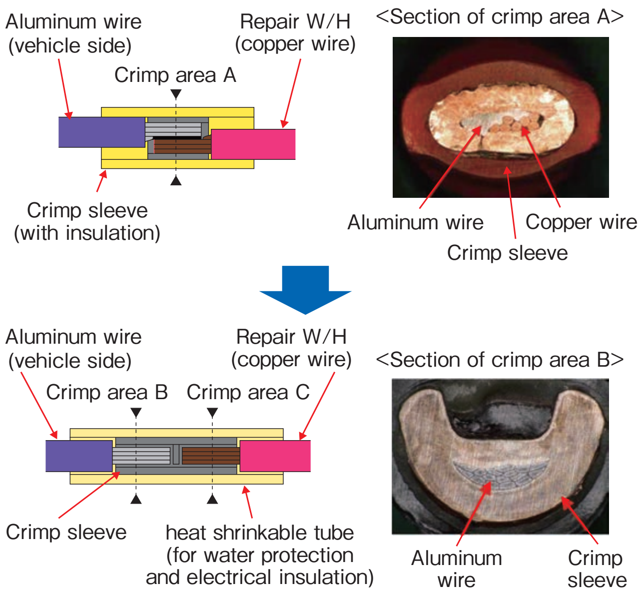

Figure 13 The repair sleeve for copper wires (top) and the repair sleeve for aluminum wires (bottom).

4. RESULTS

Until now, we have explained about the technology of the weight reduction of W/H to satisfy the requirement to reduce CO_2 aiming toward a carbon neutral society. With these mass-produced technologies, approximately 11% of W/H weight was reduced in the SUV released last year. Among them, for the seat-harness, which has a large weight reduction effect, we have replaced 115 circuits out of total 152 circuits at the maximum specification with aluminum wires (aluminum wire rate: 75%) to reduce the weight by 44%.

5. CONCLUSION

Considering the global trend toward the sustainable environment, we have forecasted that our environmental responsive technologies and products would be continuously required more and more by our society. Responding to further requirements for the weight reduction, our activities to develop the weight reduction technology for the future is essential. We will continue our development of new weight reduction technologies including aluminum wires, in order to respond to needs for weight reduction, and contribute to the realization of the carbon neutral society by the reduction in CO_2 emission.

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