特集 Development of a Cooling Module Containing a Radiator and a Condenser　Part2 : Alloy Development*

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In conventional automobile designs, a radiator and a condenser are typically configured and mounted independently of each other. We have developed a smaller and more powerful cooling module by integrating these two products into one unit. The new cooling module has been designed to share the fin material and to have an insulating slit and other means for effective prevention of heat loss that occurs due to thermal conduction between the radiator and the condenser.[1] In addition, as one of the key techniques for integrating fins, we studied thermal spraying of a brazing filler to the tube material and were able to achieve a practical-level cooling module through use of high-performance fins, and thus contribute largely to the efforts to create a more compact, higher performance cooling module.

Key words : Radiator, Condenser,Cooling module, Thermal spraying, Brazing filler, Tube material

1. INTRODUCTION

Based on recent needs of automobile manufacturers, the following major approaches to the development of vehicle cooling components are identified: (1) reducing components in overall size or width in order to meet demand for a larger interior space, (2) achieving a higher-performance and lighter condenser to reduce power consumption by the air conditioner, (3) using aluminum for all components to improve recyclability, and (4) mounting the radiator and the condenser at the same time for higher assembly line productivity. We began a study for a cooling module that can satisfy these needs.

2. MATERIAL-RELATED CHALLENGES IN MODULARIZATION

Many of our challenges faced in modularization of a radiator and a condenser come from the requirement to establish a common design for the two products that have conventionally been designed based on different design philosophies.

Figure 1 shows a comparison of the two primary components, the fin and the tube, between these heat exchangers, with a focus on materials (including brazed ones). The fin was our main target in creating a common design. As is shown in this figure, the two heat exchangers use different materials for their fins. Although there are no significant differences in their shapes. In addition, these heat exchangers use different means for feeding brazing filler to join the fin and tube.

One reason for this is that the condenser uses an extruded porous tube in order to achieve sufficient compressive strength and to improve performance. In the case of extruded materials, brazing filler is usually clad on the fin instead of the tube, since application of brazing filler on the tube's surface by cladding or other methods is difficult.

For the radiator, on the other hand, a sacrificial layer on the internal face is necessary since LLC (Long Life Coolant) flows through the tube. (Note that corrosion behavior varies depending on the extent of deterioration).

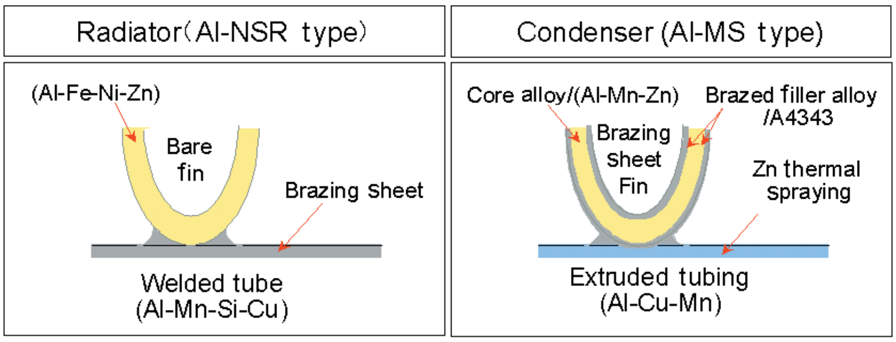

Fig.1 Materials structure of radiator and condenser

The tube, therefore, requires a cladding material to be used (i.e., a sacrificial layer is provided on the internal face and brazing filler is clad on the external face); the tube material is formed into a tubular shape by welding and then it is mated with the bare fin by brazing.

These differences caused by difference in conventional design philosophies had to be addressed in the development of a cooling module. Our basic approach to this problem was to find a way to share the fin material between the radiator and the condenser, leaving the tube side as is, since it presented too many constraints in the aspects of performance and corrosion behavior.

Table 1　Relation between fin material and product's performance

		Radiator		Condenser	
		Type	Product's Performance	Type	Product's Performance
Fin electrical conductivity	38％IACS	Clad fin	97％	Clad fin	100％
	50％IACS	Bare fin	100％	Bare fin	103％

: Current material

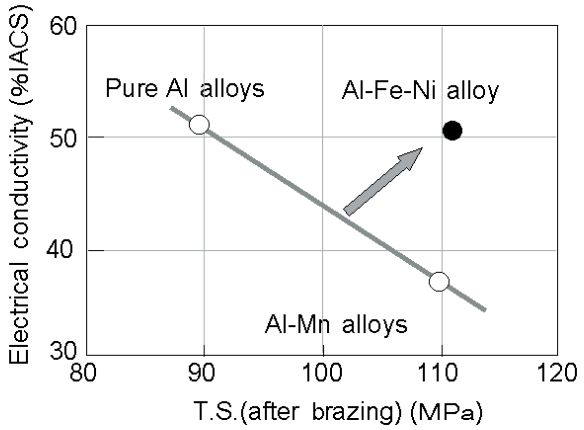

Fig.2　Properties of Al-Fe-Ni alloy

3. HIGH-PERFORMANCE FIN MATERIALS AND RESEARCH ISSUES

Table 1 shows the results of a comparison of fin characteristics. As stated above, the radiator and the condenser have conventionally used different fin materials. Looking at the results of electrical conductivity, which directly affects heat dissipation performance, the fin for the radiator (Al-Fe-Ni-Zn based) was 50% IACS, and the fin for the condenser (Al-Mn-Zn based) was 38% IACS. When designed to be a module as well, the radiator must be of an Al-Fe-Ni based material so that sufficient thermal conductivity and other necessary performance features will be assured. As for the condenser, we would be able to improve its performance 103% by using a fin material with 50% IACS, as is shown in **Table 1**. We chose a high-performance material for our cooling module's fin (**Fig.2**). A product developed jointly with Furukawa Electric Co., Ltd., it is an Al-Fe-Ni based alloy with a conductivity comparable to pure aluminum based materials while having a strength equal to Al-Mn based materials.[2)]

One possible method for applying brazing filler is to clad it to this fin. This method cannot be used on an Al-Fe based material, however, since it has smaller crystallized grains and therefore tends to buckle easily at the time of brazing due to erosion when used as a core of a clad fin. Because of this, the condenser tube has been brazed using a clad fin, which gave rise to the necessity of providing a porous mating tube with some coating against the brazing filler (**Fig.3**).

Based on these considerations, we began to develop a tube coated with a brazing filler that would enable us to achieve an effective modular design.

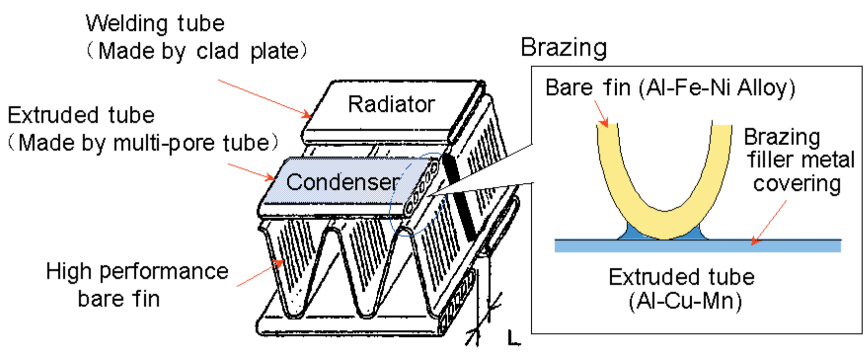

Fig.3　The structure of cooling module

4. BRAZING FILLER THERMAL SPRAYING AND TECHNICAL ISSUES

Several methods are possible for coating brazing filler, including thermal spraying. In our research, we chose the thermal sprayingmethod and investigated several approaches. Among these, we chose the DJ method since it appeared to be superior to the others, based on the results of a comparison on various items, as shown in **Table 2**. The DJ method (high velocity oxygen fuel) uses a thermal spray gun as shown in **Fig.4**, through which air, oxygen, propylene, nitrogen, and brazing filler in a powder state are fed. The typical conditions for thermal spraying are shown in **Table 3**.[3]

The technical challenges faced when thermal spraying brazing filler will now be described. In general, problems that occur when conducting brazing on a heat exchanger include fin separations (Inadequate brazed fins on one side of a specific tube), insufficient fillet forming, and erosion. Thermal spraying of brazing filler in particular tends to generate fin separations easily. When compared to cladding and other means, brazing filler thermal spraying is also more likely to generate micro pebbling and/or cavities, resulting in a lower filling density (**Photo.1**). The typical coating thickness achieved by thermal spraying is around 100 μm, and shrinkage of the coating often occurs depending on brazing thickness, which becomes significant as the number of layers increases. One way to solve this problem would be to achieve a thinner coating while at the same time decreasing micro pebbling and increasing the brazing filler density. Thus, the amount of shrinkage can be minimized if a uniform coating thickness is achieved. However, if the coating is too thin, a sufficient fillet may not be formed, resulting in bad brazing. From these considerations, it is clear that the brazing filler must be applied in an appropriate thickness with maximum possible uniformity. We studied how this requirement could be met from the aspect of both material and manufacturing method.

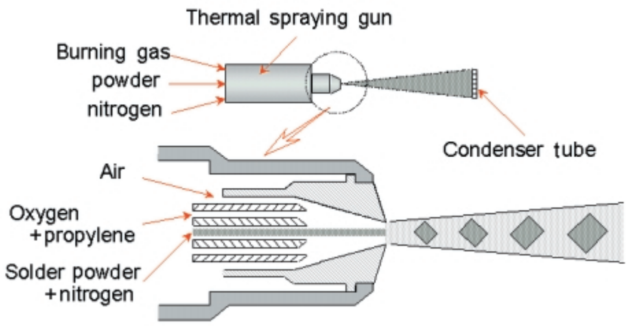

Fig.4 DJ method principle

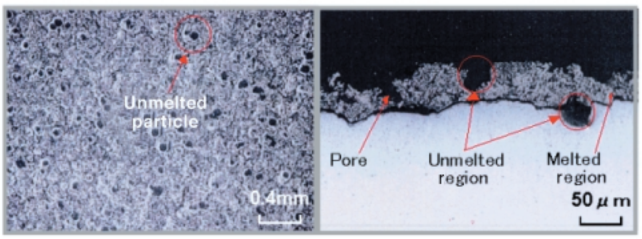

Photo.1 Surface and cross section situations after common spraying

Table 2 Comparison of thermal spraying process

Thermal spraying process	Characteristic of brazing filler metal		Resistration of thermal spraying	Equipment cost	Sprayed property		
	Shape	Chemical composition freedom			Flame temperature (℃)	Grain speed (m/s)	Strong point
DJ method (High velocity oxygen fuel)	Powder	○	○ (60%)	○	2800	900	High density
Plasma spraying	Powder	○	○ (60%)	×	16000	450	Use of refractory metal
Electric arc spraying	Wire	×	× (20%)	○	5000	250	Suitable for wide area spraying

Table 3 Operating conditions for DJ method

Condition	Oxygen	Propylene	Air	Nitrogen
Pressure (MPa)	1.0 ～ 1.1	0.45 ～ 0.55	0.50 ～ 0.55	1.0 ～ 1.1
Flow (FMR)	40 ～ 45	42 ～ 46	54 ～ 58	27 ～ 31

5. STUDY FROM THE ASPECT OF MATERIAL

During our research, we first focused our attention on the powder. In brazing, Al-12%Si, a eutectic composition, is usually used as a base. We identified two key points for the achievement of a uniform and thinner coating which we have targeted. One was the composition of the brazing filler, and the other was the particle size of the powder.

We considered the diameter of brazing filler particles to find a value that would allow the highest possible uniformity in adhesion. Since typical brazing filler powder distributes across a wide size range, it is considered to be a major cause of surface pebbling. A major cause of this pebbling is failure of brazing filler particles to melt satisfactorily. **Figure 5** shows how the melting state of the brazing filler is affected by different particle sizes. If the particle size is too large, the particle surface melts, but the unmelted part remains below the surface, causing pebbling in the coating layer. If it is too small, the brazing filler is incinerated (fumes) at the time of thermal spraying, causing the yield through thermal spraying to decrease. We studied different particle sizes, and reached the conclusion that particle sizes between 20 to 70µm give an optimum melting state, enabling us to form a uniform adhesion layer (**Photo.2**).

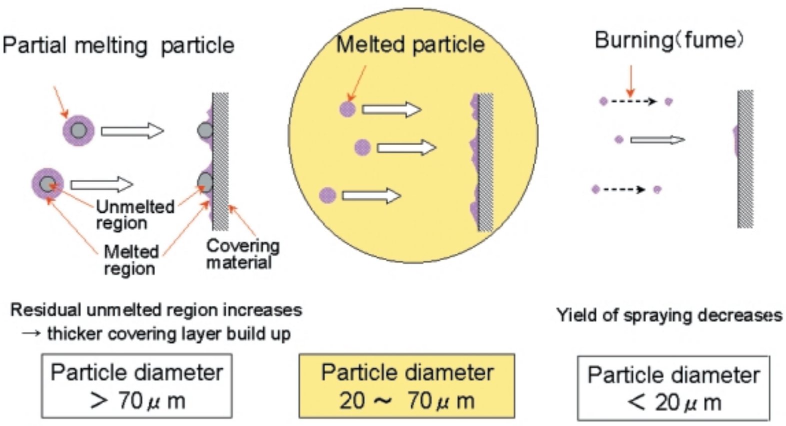

Fig.5 Relation between partial diameter and covering situation

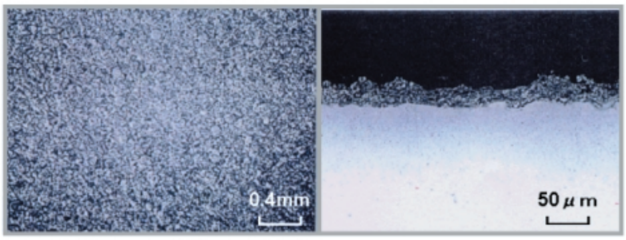

Photo.2 Surface and cross section situations after spraying (Particle diameter : 20~70µm)

We studied the composition of brazing filler, another key point, to complete brazing using the smallest possible amount of brazing filler. **Figure 6** shows the relationship between the Si content which resulted in similar fillet formation and the amounts of brazing filler that adhered. From this, we determined that increasing the Si content reduces the amount of filler required for satisfactory brazing. **Figure 7** shows this mechanism.

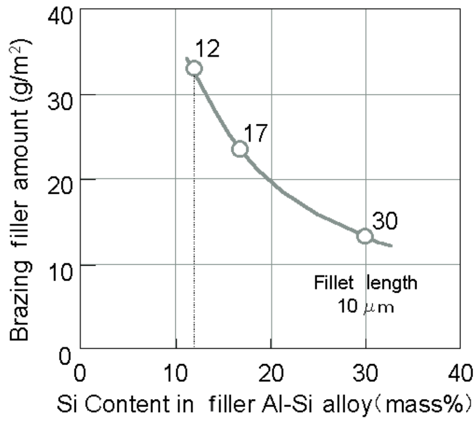

Fig.6 Relation between Si content and brazing filler amount for constant fillet length

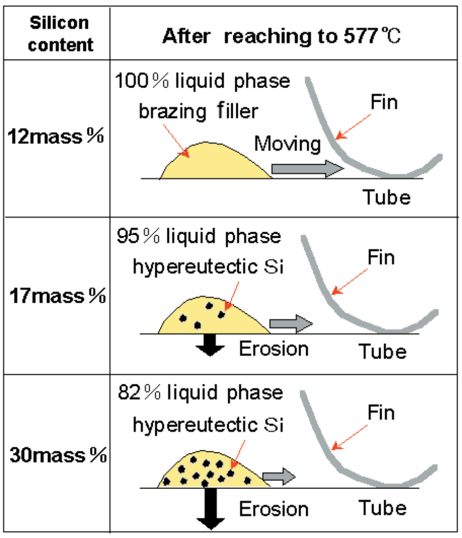

Fig.7 Brazing mechanism of Al-Si alloy

When using Al-12%Si, a eutectic composition, 100% of the brazing filler went into the liquid phase when the brazing temperature reached 577°C. The melting point of brazing filler rises when its Si content exceeds the eutectic composition; but it becomes a eutectic composition as a result of a reaction with Al, causing the liquid phase that makes brazing possible. However, if the hyper-eutectic Si contained in the brazing filler overreacts with the base metal Al, erosion occurs, giving rise to the possibility of a decrease in corrosion resistance and strength.

Based on all these considerations, we studied the relationship between Si concentration and the occurrence of erosion. **Figure 8** shows the relationship between the amount of Si contained in brazing filler and the depth of erosion. Although the results varied depending on the degree of adhesion, it was confirmed that, when the Si content exceeded 12% of the eutectic composition, the depth of erosion increased with the Si content. Since the product requirement for erosion was 10µm at maximum, we chose to use an Al-19%Si alloy.

From the considerations described above, we decided to use an Al-19%Si alloy with a particle size between 20 and 70µm of the powder to be fed as our brazing filler.

6. STUDY FROM THE ASPECT OF THE MANUFACTURING METHOD

Figure 9 shows the mass-production process of thermal spraying brazing filler powder. **Photograph 3** is a view of this process. Brazing filler is thermal sprayed from above after the particle coarsening step by shot blasting is comleted, using a thermal spray gun in the thermal spray room provided with a dust collector. In the mass-production process, the Al-19%Si alloy with particle sizes of 20 to 70µm that we developed as the powder to be fed was used as brazing filler.

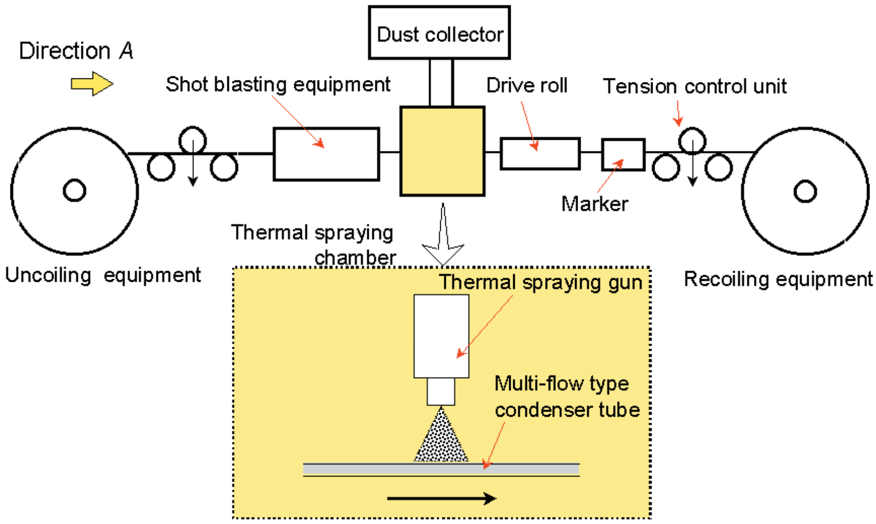

Fig.9 Thermal spraying mass production

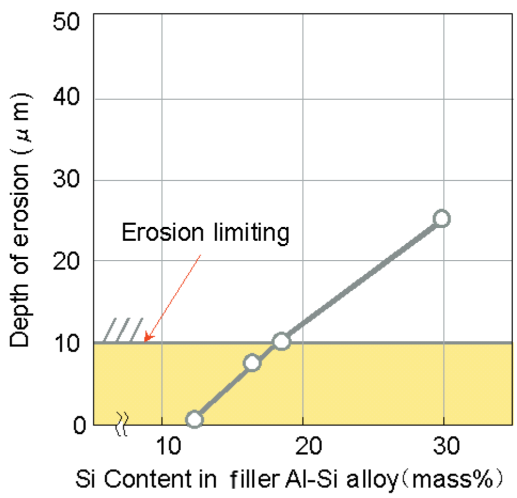

Fig.8 Relation between Si content in filler Al-Si alloy and erosion depth

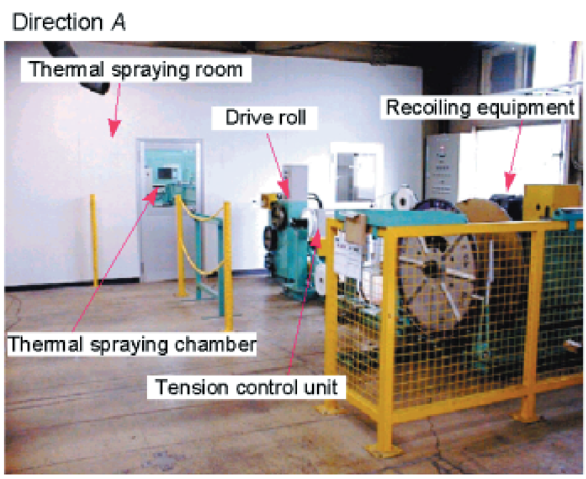

Photo.3 Thermal spraying mass production equipment

We sprayed using this equipment, and observed how fillet formation, erosion, and fin separations formed during brazing in a real-machine manufacturing setup. As described above, insufficient fillet formation occurs if the amount of brazing filler that adheres is inadequate, while fin separations are generated if the amount of brazing filler is excessive.

From these points of view, we studied the conditions which satisfied design requirements for product quality in the mass-production process. Optimized amount of brazing filler control enabled to make the appropriate manufacturing processes. Finally, we observed the generation of erosion. Whenever the amount of brazing filler that adhered was within the range of manufacturing conditions, no significant erosion was found, demonstrating that the results were far above the specifications required for the product quality.

7. CONCLUSION

We identified an aluminum-brazed alloy with favorable brazing characteristics (Al-19%Si), which maintained its particle sizes in a range between 20 to 70μm, and thermal sprayed it in a melted state using the DJ method (high velocity oxygen fuel). This resulted in a higher-density brazing filler layer, which enabled us to decrease the thickness of the layer and also to decrease pebbling on the surface (i.e., a more uniform thermal spraying). By this, fin separations (Inadequate brazed fins on one side of a specific tube), brazing tears, and other problems were eliminated, making a great contribution to the creation of a cooling module with high-performance fins.

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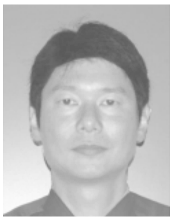

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