

Development of Metal Clad Sheets and Strips

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Abstract

We have established a mass production technology of metal clad sheet and strip by the warm rolling joining process in the Naoetsu Works, and we are providing the material sheet mainly used for kitchen utensils on IH cooking instrument. Our clad sheets are made on the basis of the combination of two layers or three layers that assumed aluminum as a matrix material, and we can choose various stainless steel or titanium as laying upon materials. We realize new feature and high function to conventional materials by making materials choice depending on a purpose of use.

1. Introduction

Clad sheets and strips (hereinafter “clad”), consisting of laminated layers of dissimilar metals, can be formed into multi-functional materials that enable new functions that conventional metallic materials could never achieve. Laminated materials that are appropriate to the purpose are selected. In 1988, Naoetsu Works of Nippon Steel & Sumitomo Metal Corporation established mass-production technology for wide SUS/Al clad coils, by applying the warm rolling and joining methods.^{1,2)} The materials are used mainly for electromagnetic cooking appliances such as kettles, frying pans and induction heating (IH) rice cooker inner pots. Clad sheet coils are basically two or three layers of laminated stainless steel and an aluminum matrix material. It should be noted that use of a material other than stainless steel is also possible. A laminate consisting of titanium and Fe-Ni alloys laminated on aluminum is also produced to a certain extent.

This report introduces joining methods for the clad sheets, relevant mass-production equipment, and characteristics of existing products.

2. Clad Material

Figure 1 shows how clad material becomes functional when dissimilar metals with different metallic characteristics are laminated into a single sheet. The composition is designed to make up for the shortcomings of other materials, simultaneously utilizing the advantageous characteristics of each metal which, as a whole, provides a unique sophisticated function. For example, IH appliances use of magnetic stainless steel as a heating element. However, localized overheating tends to take place because the heat conductivity coefficient is low, creating the possibility of burning during use. This is

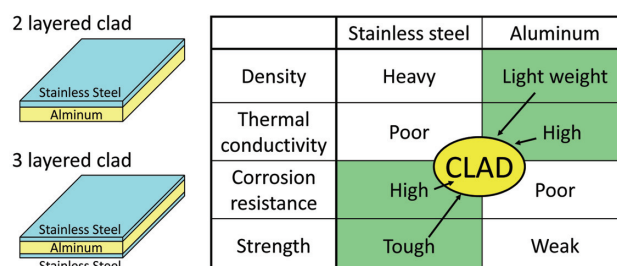


Fig. 1 Realization of high function by the laminating of different kind metal

why stainless steel having strong IH heating characteristics is laminated on aluminum, which has a high heat conductivity coefficient; this permits sophisticated functions, by simultaneously taking advantage of the IH exothermal characteristics of stainless steel (ferrite family) and the heat conductivity characteristics of aluminum. Figure 2 shows the thermal distribution of an empty SUS-made single layered pot and an empty SUS/Al/SUS three layered pot, when heated by an IH cooking apparatus. Observations demonstrated the avoidance of localized heating at the bottom of the pot immediately above the IH coils, with the heat transferred effectively to the pot sides, even though IH coils are not installed there.

3. Method of Joining Coils for Clad Material

There are several methods for joining metals to make a clad material. These methods include explosive bonding, weld overlaying and the rolling method. The rolling method is preferred for mass production of clad sheet coils.

For example, clad sheets consisting of only ferrous materials can be produced by the layered rolling method.³⁾ Nippon Steel & Sumi-

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tomo Metal produce stainless steel clad sheets having an SUS/Fe/SUS structure by hot-rolling a slab fabricated by electron beam welding (EBW) in an evacuated state. This produces a hot-rolled coiled sheet which is then cold-rolled into a sheet coil. **Table 1** shows an example of three layered SUS/Fe/SUS products produced by this process.

When aluminum is used as the matrix material, special evacuated equipment or an atmosphere-controlled reheating furnace are not required. In this case, the warm rolling joining method that allows

heating in open air can be used. This results in reduced equipment construction costs and better equipment maintenance performance.

Figure 3 shows a schematic of the production equipment for wide clad sheet coils at Naoetsu Works. The line process consists of heating the coils in-line, and then immediately joining them by the rolling method. As a result, clad coil production can be achieved by a single process.

In this process, a four-high rolling mill with a pair of 250 mm diameter work rolls is used. The maximum allowable load of the mill is 1,350 tonf. The production line normally produces 914 mm wide sheet coils and is capable of widths up to 1,000 mm. In order to achieve consistent joining strength and quality, a uniform material temperature distribution and a rolling reduction ratio in the width direction are required. For this purpose, various countermeasures are employed using the plant equipment. These countermeasures include technology to uniformly heat the material by a direct current-carrying system as shown in **Fig. 4**,^{4,5)} and back-up VC rolls for the rolling mill.⁶⁾ **Figure 5** shows peeling strength distribution in the width direction of the sheet, which is a direct result of using this production line. **Table 2** shows the dimensions of the clad material produced in this process.

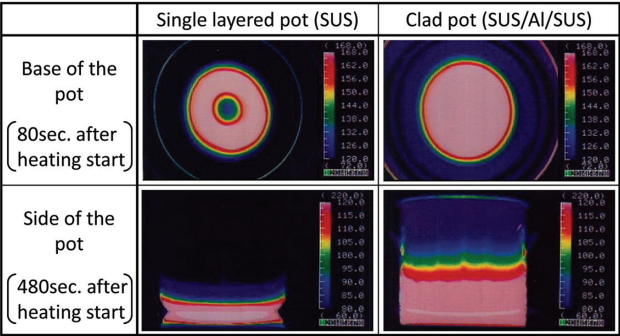


Fig. 2 Surface temperature distribution of empty pot in the heating test using IH cooker

Table 1 Example of SUS/Fe/SUS clad product			
Combination	Thickness (mm)		Width (mm)
	Total	SUS (×2)	
SUS-Steel-SUS (SUS 304L/SPCE/SUS 304L)	0.6 - 2.5	10% of total thickness	Max.1280

Table 2 Example of SUS/Al clad product			
Combination	Thickness (mm)		Width (mm)
	Total	SUS, Ti	
SUS-Aluminum (SUS/Al, SUS/Al/SUS)	0.6 - 3.3	0.3 - 0.8	≤ 914 (Max.1000)
Titanium-Aluminum (Ti/Al, Ti/Al/Ti)	0.6 - 2.5	0.3 - 0.7	≤ 914 (Max.1000)

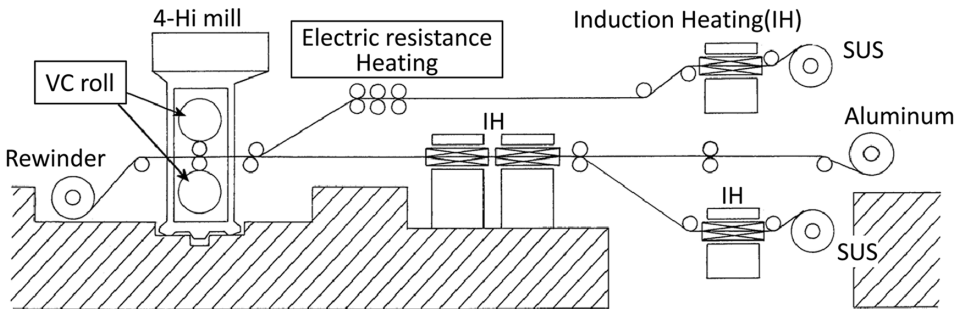


Fig. 3 Outline of the clad coil production line

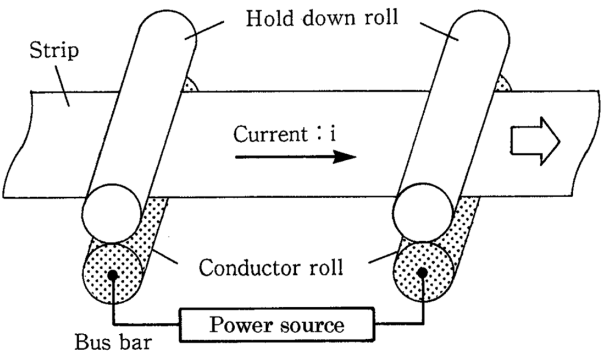


Fig. 4 Schematic outline of the electric resistance heating

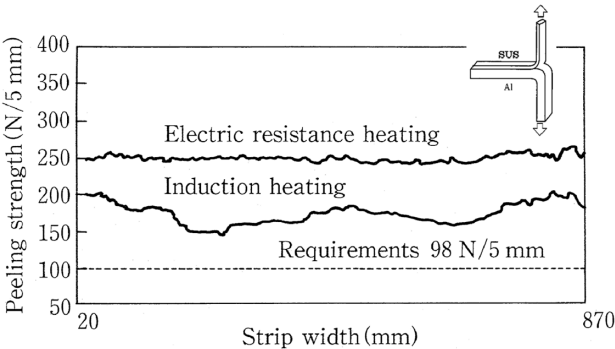


Fig. 5 Effect of the electric resistance heating for the distribution of peeling strength

4. Development of SUS/Al Clad Products

As stated in the introduction, clad materials produced at Naoetsu Works are composed of an aluminum matrix material and a selection of laminated stainless steels or other metals, depending on the purpose. Hereinafter, this paper introduces characteristics of applied clad materials mass-produced until now.

4.1 Clad materials for cooking apparatus (NAR160/Al, NAR160/Al/SUS304L)

As previously stated, a clad material made of stainless steel (ferrite family) and aluminum has both IH exothermic and heat conductivity characteristics, and is therefore widely used for IH cooking apparatus. Clad materials are normally press-formed into pot-like shapes for cooking apparatus. This requires that the material possess high formability. However, as opposed to single layer sheet material, clad sheet material exhibits complicated behavior during press-forming. This motivated the development of application technologies with improved bending formability, deep drawing formability and the like. **Figure 6** shows the effect of sheet holding pressure and heat treatment on the bending formability of a three-layered clad material. Under small sheet holding pressure, the radius of curvature of the sheet after bending becomes smaller than the radius of the bending tool tip (over-bent). It was confirmed that this phenomenon leads to the development of cracks on the outer surface.⁷⁾ Characteristic findings of this kind concerning the forming of clad material are compiled for various forming conditions. Practical applications of clad sheets are supported by proposals of appropriate forming conditions.

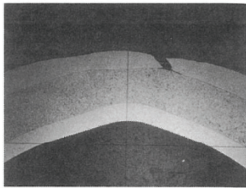

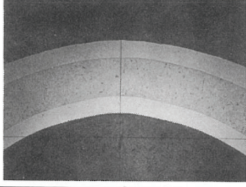
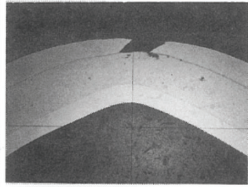
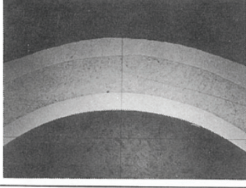
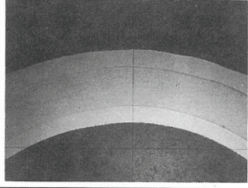
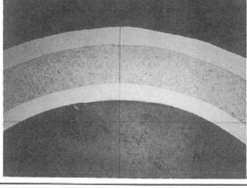
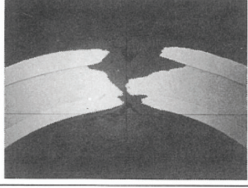
Bending ⇒ Rev. bending: radius=5mm	Bending radius=5mm	Flange weight pressure (kgf/mm ²)	
Annealed (400°C × 30min.)	As Rolled		
		0.7	
		1.5	
		3.0 ~ 5.1	
		6.0	

Fig. 6 Appearance after the bending test of clad sheet by various conditions (3 layered SUS/Al/SUS, 2.0 mm in thickness)

4.2 Clad sheets as a material for IH rice cooker inner pots (Cu/NAR160/Al)

An IH rice cooker is capable of cooking rice very effectively by taking advantage of high heating power and efficiency. Its kitchen-use rate exceeds 70%, and is continuing to grow. PANASONIC Corporation sells products with externally copper-plated inner pots to enhance IH efficiency, as shown in **Fig. 7**. The copper-plating is applied to the material before press forming; Cu/SUS/Al clad sheet is primarily used, and is produced by copper-plating the SUS surface of the SUS/Al clad material cut into a circular shape.

Plating treatment needs to be applied only to the SUS surface without causing any damage to the aluminum surface of the SUS/Al clad sheet by protecting the aluminum surface from corrosion, which may be caused by an alkaline degreasing solution or plating treatment solution. Also in that case, it is necessary to consider the suppressing thermal deformation of the bimetal clad material. For this purpose, a coating jig was developed for specific use for the circular clad sheet. Therefore, copper-plating only to the SUS surface has been established (**Fig. 8**).

Furthermore, in order to obtain high IH heating efficiency through formation of the copper-plate-layer, strict control over plate film thickness is required.⁸⁾ However, plate film thickness changes due to stretch and elongation of the side at the time of subsequent press-forming. Therefore, film thickness design, which takes into account the reduction in plate film thickness due to the stretch and elongation, becomes necessary. For this purpose, a technology that controls the current distribution of the plating treatment was developed utilizing FEM analysis. The plate film thickness appropriately varies in the radial direction of the circular plate material.

4.3 Clad materials for disc brakes (SUS403/Al/SUS403)

Troubles in disc brakes due to excessive generation of heat can



Fig. 7 Copper plated clad pot for the IH rice cooker (Cu/SUS/Al, 1.5 - 2 mm in thickness)



Fig. 8 Copper plating equipment for Cu/SUS/Al clad

be prevented by applying a three layer clad material, consisting of SUS/Al/SUS, to the associated sliding parts. For this purpose, a three layer material consisting of quenched SUS403 laminated on both surfaces of the aluminum matrix material has been developed for use as the rotor of the disc brake system for racing mountain bicycles.

Quenched SUS403 has excellent abrasion resistance, so is used as a laminating material for sliding surfaces; however, since the quenching temperature of SUS403 is higher than the melting point of aluminum, quenching heat treatment of clad material after joining is impossible. Therefore, in the rolling method for joining, it is necessary to laminate and join high strength aluminum matrix material after the quenching heat treatment. As high strength materials have poor ductility in the rolling process, and as the area of the newly exposed surface is small, maintaining sufficient joining strength is difficult. Furthermore, although high sheet thickness accuracy and flatness are generally required for sliding parts, the process of single roll joining has difficulty achieving high sheet thickness accuracy. In order to solve these problems, clad coils are provided with post re-rolling under appropriate conditions after joining. This has achieved sufficient joining strength, sheet thickness accuracy and flatness.

4.4 Titanium/aluminum (Ti/Al) clad material

Compared to steel or stainless steel, titanium has excellent corrosion resistance, light weight and high specific strength. Higher functionality, together with further weight savings and enhanced heat radiating characteristics, can be achieved by joining titanium and aluminum to make clad material. Since work hardening of titanium in the rolling method of joining is less than that of stainless steel, Ti/Al clad material has high ductility after joining, and excellent bending and drawing formability characteristics, as shown in Table 3. Furthermore, because Young’s modulus of titanium is smaller than that of stainless steel, significant spring back is generated when a titanium sheet is formed independently. However, as Fig. 9 shows, the amount of spring back can be controlled by utilizing Ti/Al clad material.⁹⁾

Furthermore, surface treatments of Ti/Al clad material are easier than those of SUS/Al clad material, and both anode oxidation treatment of the titanium surface and alumite treatment of the aluminum surface are possible. Figure 10 shows examples of Ti/Al clad materials with the titanium surfaces processed for color-development.

Due to these characteristics, Ti/Al clad material is appropriate for parts where appearance is considered important, and where high formability is required.

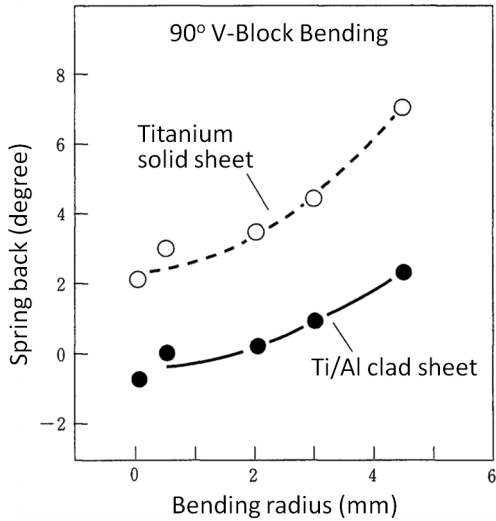


Fig. 9 Spring back of the Ti solid and Ti/Al clad sheet

Color development example

- Specimen : Ti/Al clad sheet
- Processing side : Ti surface
- Method : Anodizing color development

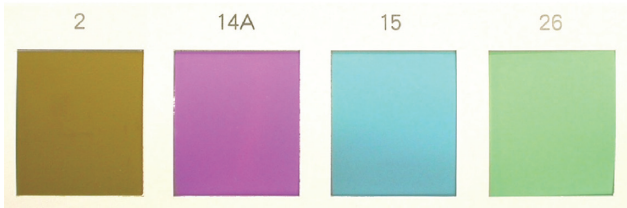


Fig. 10 Color development example by the anodizing of the Ti/Al clad (Ti side surface)

5. Conclusion

A mass production technology for SUS/Al wide clad sheet coils, utilizing the warm rolling method of joining, has been established. Furthermore, in addition to standard SUS/Al clad material, other clad materials such as Cu/SUS/Al, Ti/Al, and SUS/Fe/SUS, have been developed, and unique functions for them have been realized.

Hereafter, the development of various applications can be expected by taking advantage of the rich versatility of these materials, assessment technologies, and application technologies owned by Nippon Steel & Sumitomo Metal.^{10, 11)}

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Table 3 Workability of the Ti/Al clad

Material	Thickness	Drawing test		Bend test (180°)
		direction	L.D.R	
Ti/Al	0.8 mm		2.38	Good
			2.40	Good

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