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ScienceDirect
Trans. Nonferrous Met. Soc. China 28(2018) 9−19
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Deformation and heat treatment ability of three-layer 6009/7050/6009 Al alloy clad slab prepared by direct-chill casting

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Received 12 August 2016; accepted 24 March 2017

Abstract: Three-layer 6009/7050/6009 aluminum alloy clad slab was fabricated by an innovative direct-chill casting process. To study the response of the clad slab to plastic deformation and heat treatments, homogenization annealing, hot rolling, solution and aging were successively performed on the as-cast 6009/7050/6009 clad samples. The results revealed that excellent metallurgical bonding between 7050 alloy layer and 6009 alloy layer was achieved under optimal parameters. The clad ratio obviously decreased when the annealed sample was rolled to 55% hot reduction level, and then changed slightly with further rolling. Furthermore, the content of rodlike Zn-rich phases increased significantly in 7050 alloy layer in the homogenized clad samples after rolling at 55%, 65% and 75% hot reduction levels, and the higher level of hot reduction resulted in narrower diffusion layer. Subsequent solution and aging significantly improved the hardness in 7050 alloy layer, interfaces and 6009 alloy layers of the rolled samples except for the thin side for the 75% hot reduction sample.

Key words: aluminum alloy; three-layer clad slab; direct-chill casting; plastic deformation; heat treatment

1 Introduction

Metal matrix composites particularly offer the intrinsic advantages of additional properties which benefit from the addition of dispersed particles [1], fibers [2], or layers [3]. As described by KOCICH et al [4], the development of new composites becomes more and more important in materials research field. Among them, the multilayer composite plates are of significant interest for application in many industrial fields, which results from their comprehensive physical, chemical and mechanical properties [5]. Multilayer composite materials were usually prepared by centrifugal casting [6] and laser cladding [7]. Besides, explosive welding was used to prepare magnesium AZ31−aluminum 7075 composite, aluminum and copper plates and other metal plates [8−10]. Furthermore, the similar/dissimilar light metal sheets, Mg/Al clad and stainless steel/aluminum sheet have been developed by diffusion bonding [11−13]. Recently, several new forming technologies have been applied to manufacturing clad composites. For example, the 6xxx/5xxx/6xxx aluminum clad sheets, 7075 Al/Mg−Gd−Y−Zr/7075 Al laminated composite and Mg/Al laminated composite were fabricated through rolling bonding [14−16]. Moreover, KOCICH et al [3,4] used the rotary swaging process to fabricate the clad composites, though the non-uniform strain distribution through the cross-section of a swaged rod was its potential disadvantage.

However, the above processes have the problem of low bonding strength between different metal layers. The direct-chill casting is an ideal method for producing multilayer clad slab as it can solve the problem of low bonding strength, as well as its lower cost and high productivity. The Novelis fusion process was used to manufacture the clad ingot [17]. SUN et al [18], JIANG et al [19] and LIU et al [20] prepared the Al−Si alloy and Al−Mn alloy clad aluminum by direct-chill continuous casting. What's more, in our previous work the 6009/7050 clad ingot developed by direct-chill casting was reported, and its characteristics evolution was also investigated [21,22].

The three-layer 6009/7050/6009 clad slab using 6009 alloys as protective layers, would be expected to improve the corrosion resistance of the high-strength

Foundation item: Projects (51375070, 51574058) supported by the National Natural Science Foundation of China
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DOI: 10.1016/S1003-6326(18)64633-3

7050 alloys as well as formability. In this work, the 6009/7050/6009 three-layer clad slab was produced by an innovative direct-chill casting process. More attention was paid to the plastic deformation and heat treatment behaviors of the 6009/7050/6009 three-layer clad slabs, owing to the importance in the potential use in airplane industries of this clad slab and similar composite ingots in commercial applications. The evolution of microstructures, composition distribution and mechanical properties of the as-cast clad slab after plastic deformation and heat treatments were studied in details.

2 Experimental

2.1 Materials and ingot preparation

The experimental materials including 7050 alloy melt and 6009 alloy melt were prepared separately by melting the commercial pure aluminum, zinc, copper, magnesium, manganese, crystalline Si and Al−4%Zr master alloy at appropriate ratios in their respective pot resistance furnaces. Fluorometric analysis was used to measure the chemical compositions of the 6009 alloy layer and 7050 alloy layer and the results were presented in Table 1. The three-layer 6009/7050/6009 clad ingot was prepared by an innovative direct-chill casting process. Figure 1 reveals the schematic illustration of experimental apparatus. The results demonstrated that two same water-cooled baffles were placed in the mold in parallel and divided the mold inside into three sections symmetrically. The pouring process and solidification process of the 6009/7050/6009 clad ingot resemble that of 6009/7050 bimetal slab, mentioned in our previous work [21]. The three-layer 6009/7050/6009 aluminum clad slab (150 mm × 120 mm × 100 mm) was finally obtained. The optimized experimental parameters were gained after a battery of systematic experiments: the pouring temperatures of 6009 melt and 7050 melt were 715 °C and 720 °C, respectively, the drawing speeds of two water-cooled baffles were both 70 mm/min, and the cooling water flow rates of two water-cooled baffles were both 140 L/h.

Table 1 Chemical compositions of experimental alloys (mass fraction, %)

Alloy	Zn	Cu	Mg	Si	Fe	Zr	Mn	Cr	Al
7050	6.57	2.04	1.97	0.093	0.114	0.09	0.003	0.021	Bal.
6009	−	−	0.41	0.792	0.134	−	0.004	0.018	Bal.

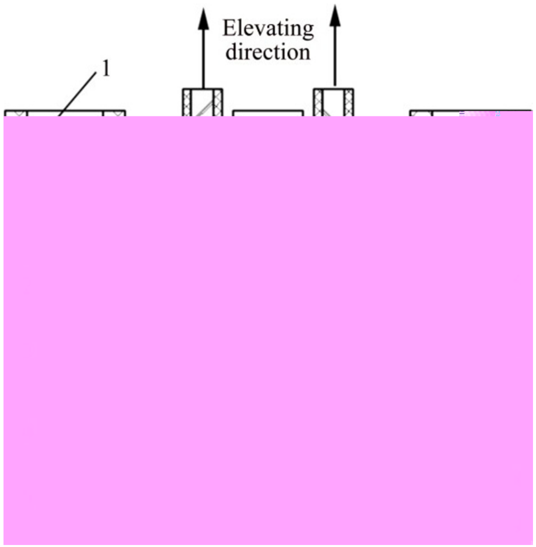

Fig. 1 Schematic illustration of modified direct-chill casting process: 1—Hot top; 2—Mold; 3—Water cooled baffle; 4—6009 alloy melt; 5—6009 alloy semisolid shell; 6—Heat insulation layer; 7—7050 alloy melt; 8—7050 alloy semisolid shell; 9—Clad slab

2.2 Plastic deformation and heat treatments

A test sample with a length of 130 mm, a width of 80 mm and a height of 50 mm, was prepared by wire-electrode cutting technique from the as-cast three-layer 6009/7050/6009 aluminum clad slab and the thickness for the thin 6009 layer, 7050 layer and thick 6009 layer of the test sample was 8, 60 and 12 mm, respectively. In this work, the interfacial region on 8 mm 6009 layer side was called the interface for the thin side, while the interfacial region on 12 mm thick 6009 layer side was called the interface for the thick side. Figure 2 shows the heat treatment and plastic deformation

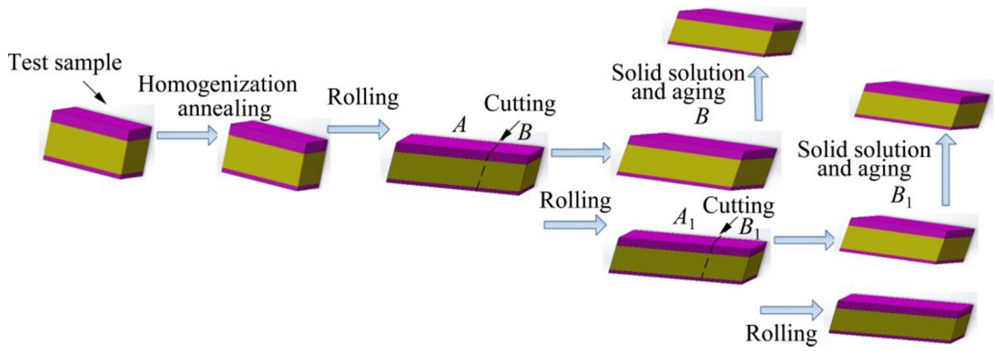

Fig. 2 Schematic illustration of heat treatment and plastic deformation procedures of 6009/7050/6009 clad samples