ROLLING DEFORMATION LAW OF ALUMINIUM ALLOY CLAD SHEET①

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ABSTRACT The rolling deformation laws of Al-Si/Al-Mn tri-layer clad sheet were investigated, which include the changing law of clad rate (ratio of clad thickness), the relationship of deformation speed of matrix material and clad material, the heterogenous distribution of thickness of clad layer, and the clad process of matrix material and clad material. The results show that in whole rolling process, the thickness of clad layer is heterogenous along the width direction, the changing at the edge is larger at the center, and the heterogeneity has heredity. At the beginning of cladding, the deformation of clad layer is larger than that of matrix, the clad rate descends rapidly, but the clad rate decreases gradually with rolling developing. After cladding, the cladding rate and the ratio of μ_c/μ_m keep unchanged. In the whole rolling process, the deformation speed of clad layer is always larger than that of matrix, but the changing tendency of their speeds is identical. The clad process of matrix metal and clad metal can be divided into 3 stages: free (slip or nonrestraining) deformation stage, partial restraining (partial clad) deformation stage, full restraining (full clad) deformation stage.

Key words aluminium alloy clad sheet rolling deformation deformation law

1 INTRODUCTION

Al-Si/Al-Mn tri-layer brazed clad aluminium sheet is the main material for making evaporator and cooler in the air conditioner of the automobile and cooler as well in the cooling system of the engine. The thickness of the final products, physical property and combined strength of the above Al-Si/Al-Mn sheet are strictly required; besides, the thickness and uniformity of the clad layer also directly affect the quality of the braze welding of the clad sheet. The domestic and foreign standards strictly stipulate the clad rate[1,2]. The allowable clad rate of aluminium alloy clad sheet for the heat exchanger is 10%~15%. It is very important to make certain the clad sheet deformation law for the solution of the problems of combined strength, clad rate and homogeneity of the clad sheet.

2 EXPERIMENTAL METHOD

3003 alloy was used as the matrix material and 4004 alloy as the clad material. The chemical compostitions of the two materials are listed in table 1. The initial clad rates 9%, 11%, 13%, 15%, 17%, respectively.

Table 1 Chemical compositions of materials(%)

Alloy	Cu	Mg	Mn	Fe	Si	Zn	Ti	Al
3003	0.06	-	1.15	0.38	0.12	0.01	0.01	Balance
4004	0.01	1.7	0.03	0.22	9.88	0.02	0.01	Balance

The surfaces of the two materials must be treated before the rolling cladding. The hot rolling cladding was carried out on the 2800 mm rolling mill for sheets and strips and the temperature was 490 ℃.

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The thickness of the clad layer of each rolling stage was measured to confirm the clad rate and deformation speed of the matrix metal and clad metal. The combined strength of the interface was determined and the micrograph of the clad sheet was observed.

3 RESULTS AND DISCUSSION

3.1 Changing law of thickness of clad layer along sectional direction of clad sheet

The thickness change of the clad layer of the clad sheet along sectional direction after hot rolling is shown in Fig.1, apparently, the thickness along sectional direction is not uniform. The change of the two curves are similar. Near the edge of the sheet the change is fairly large, but in the middle part it is almost unchanged due to the flow speed of metal at the edge and middle being inconsistent and the flow of the edge metal being nonuniform, which results from the nonuniform distribution of the unit pressure along sectional direction. The fact that the thickness changes in every period after rolling are almost consistent shows that the nonuniformity

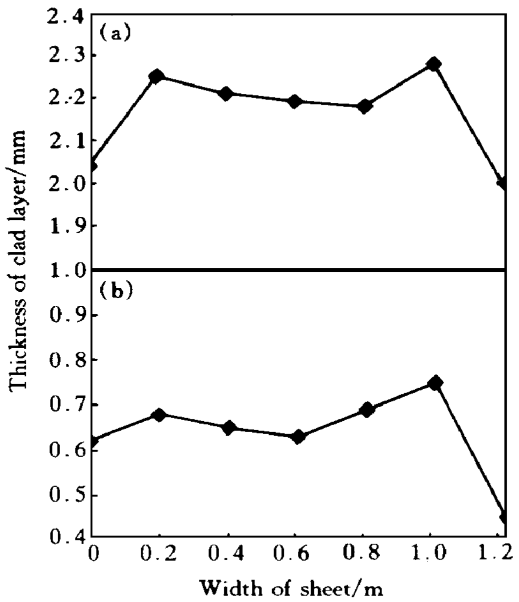

Fig.1 Distributions of thickness of clad layer along sectional direction of clad sheet
(a) —Hot roughing; (b) —Hot finishing

has certain heredity, so the nonuniform change of the thickness in the early hot rolling period must be strictly controlled.

3.2 Changing law of clad rate

The plastic deformation behaviour of the multilayer clad sheet is very complicated during rolling process. Before and after cladding the thickness change of every layer is different because the flow stress among all metal constituents is different. Therefore, after the billet with different initial (unclad) clad rate is rolled, the clad rate after cladding will change.

For the billet with a certain initial clad rate, after hot rolling, the change of the current clad rate is shown in Fig.2. Thus it can be seen that during the whole rolling the clad rate descends rapidly when the reduction is lower and it descends slowly when the reduction is over the critical value and it becomes a constant when the reduction is over 30%.

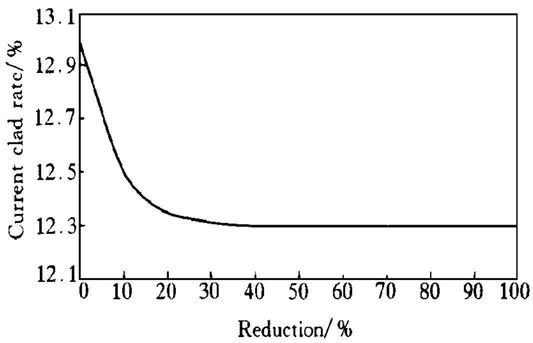

Fig.2 Clad rate changing with deformation during rolling
(rolling at 490 ℃, initial clad rate being 13%)

After the billet with different initial clad rates is rolled through the same process, the change of the current clad rate is shown in Fig.3. From the figure it can be seen that there is a linear relationship between initial clad rate and current clad rate. The current clad rate increases with the initial clad rate increasing. Moreover, under the same condition, the difference between them is not very large. According to the stipulation of the relevant standard, the clad rate of a brazed sheet should be 10% ~ 15%, so the initial clad rate should also be 10% ~ 15%.

3.3 Relation between clad layer and matrix deformation speeds

The change of the clad rate of clad sheet occurs primarily in hot roughing process (Fig.2) . Maybe the main cause arousing the change is that there is a difference between the deformation speed of clad layer and matrix metal, so it is necessary to study the relation of the deformation speeds of the two materials during rolling.

According to the data obtained by test and theoretical calculation, the deformation speeds of the matrix and clad layer during the rolling are shown in Fig.4. From Fig.4(a) , (b) it can be seen that during the whole rolling process, the deformation speed of the clad metal and matrix metal increases with reduction increasing, when the reduction is over 70 %, it increases more rapidly. From Fig.4(c) it can be seen that the specific value of both deformation speed continuously decreases as the total reduction increases. During the early hot roughing period, the specific value decreases rapidly, but after it is over 20 %, it gradually closes to 1, which shows that during the whole rolling process the deformation speed of the clad layer is always larger than that of the matrix, but the changing tendency for both deformation speeds is consistent.

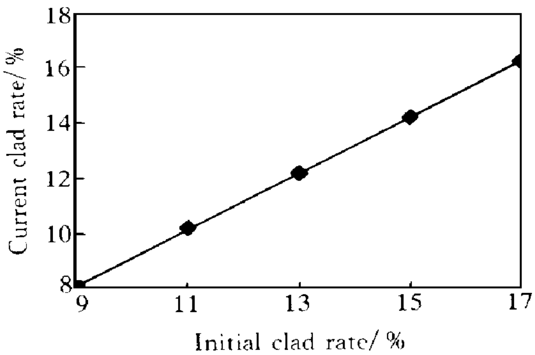

Fig.3 Relation between initial clad rate and current clad rate

In order to exactly illustrate the change of deformation speeds of clad metal and matrix metal during the rolling process, a regression analysis of the test results is done. Regression equations are as follows:

$$\left.\begin{aligned} v_c &= 0.5023 + 0.09769\,\varepsilon \\ v_m &= 0.3220 + 0.05479\,\varepsilon \end{aligned}\right\} \quad (\varepsilon \leqslant 70\ \%)$$

$$\left.\begin{aligned} v_c &= \exp(-7.460 + 0.1143\,\varepsilon) \\ v_m &= \exp(-7.885 + 0.1141\,\varepsilon) \end{aligned}\right\} \quad (\varepsilon > 70\ \%)$$

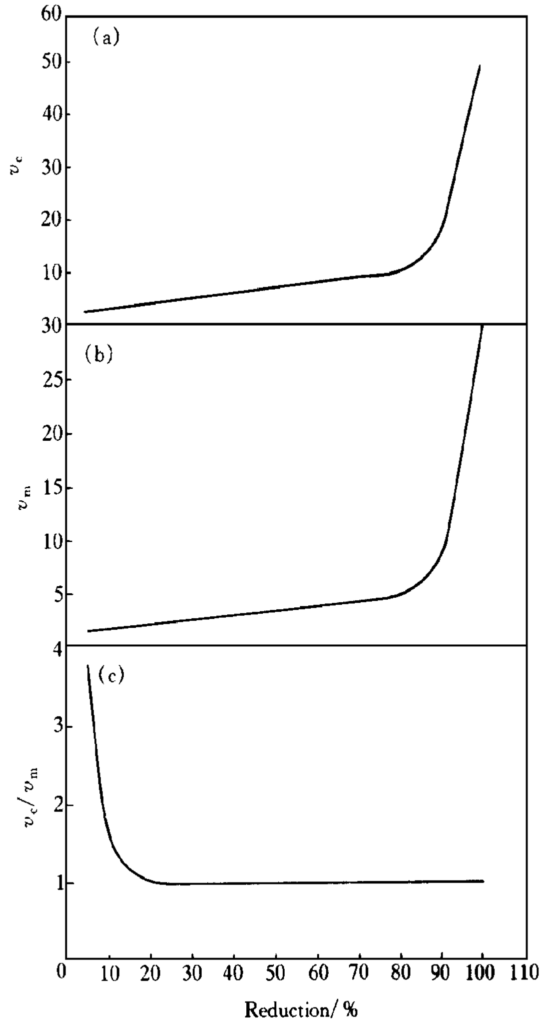

Fig.4 Relationships of changes of v_c(a) , v_m(b) , v_c/v_m(c) of clad sheet with reduction during rolling
(rolling at 490 ℃, initial clad rate being 13 %)

From above regression equations it can be seen that the changing tendency of deformation speeds of clad metal and matrix metal is consistent with that of total rolling reduction. If reduction is less than 70 %, both of them increase linearly as total reduction increases. If reduction is over 70 %, the relationship of their speed changing with total reduction is exponential function.

3.4 Analysis of clad process

During the early hot rolling period, every constituent of both materials is not binded, and so a clad sheet is under a free deformation condition. As its reduction at the beginning is low, the plastic deformation is difficult to be deep into the matrix material, the deformation of clad metal is larger than that of the matrix metal, so the value of v_c/v_m is high (Fig.4(c)) and the clad rate begins to descend rapidly (Fig.2). Along with the clad sheet rolled, the surfaces of the two metals begin to rupture so that the deformation of the clad layer is inhibited to a certain degree and the deformation of matrix metal increases, thus v_c/v_m descends rapidly and the tendency of the descension of the clad rate becomes weaker. When the reduction reaches a critical value, the film of interface ruptures completely[3] and the fresh metals are exposed to realize a physical contact (Fig.5), meanwhile, a

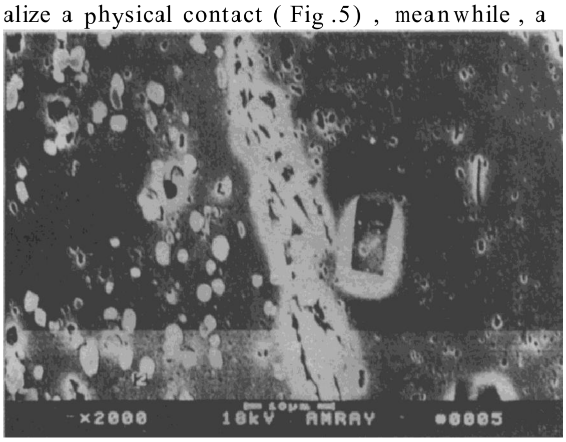

Fig.5 Interface morphology of clad sheet after 19.5 % reduction at 490 ℃

large quantity of metallic binding points between the constituents of interface occur. The deformation of two metals restrains each other so that the clad rate and v_c/v_m gradually tend to constant values. Along with the increase of reduction, the deformation speeds of clad metal increase further, and the temperature is fairly high during the rolling so that the atoms diffusion at the interface becomes larger, the interface combinaton changes from point combination to face combination[4].

The combination interface is difficult to be distinguished, only by the texture can it be done (Fig.6), so that the deformation of two metals restrains each other seriously and the clad rate basically does not change. Because the deformation resistance of two metals is different, the deformation of two metals is different and the specific value of v_c/v_m almost keeps at 1.75, which illustrates that the deformation speed of the layer is larger than that of the matrix, but the changing tendency for both deformation speeds is to be consistent. After the rolling is finished, the combined strength at the interface of a clad sheet is 99.5 MPa and approaches 105 MPa of the shear strength of matrix 3003 alloy, which shows that the two metals are firmly combined.

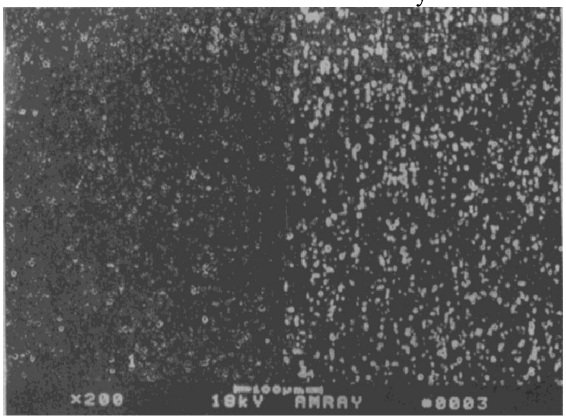

Fig.6 Interface morphology of clad sheet after hot rough rolling

4 CONCLUSIONS

(1) During the rolling, the thickness of clad layer of clad sheet along sectional direction exists nonuniformity. Near the side of a sheet the change is fairly great and in the middle part it almost does not change, the heterogeneity has some heredity.

(2) At the beginning of rolling of clad sheet, as the reduction is minor, the clad metal deforms before matrix, the specific value of v_c/v_m is great and the clad rate descends rapidly. Along with the clad layer rolled, its deformation is inhibited to a certain value, the v_c/v_m de-

scends rapidly. At the same time, the clad rate descends slowly. After the clad layer and matrix is welded, the clad rate and v_c / v_m basically remain unchanged. During the whole rolling process, the deformation speed of clad layer is always greater than that of the matrix, but the changing tendency for both deformation speeds is consistent.

(3) The whole clad process of matrix metal and clad metal can be divided into 3-stages: free (slip, nonrestraining) deformation stage; partial restraining (partial clad) deformation stage; full restraining (full clad) deformation stage.

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