Study on the pack rolling process factor of Ti-6Al-4V alloy

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Abstract

Pack rolling method is preferred to conventional rolling method to process thin sheets or foils out of titanium alloys because of their relatively narrow processing window and possible surface contamination during the elevated temperature processing. In this paper, the core sheets of 5mm thick with equiaxed alpha + transformed beta structure were encapsulated in mild steel cover material and hot rolled in a four high reversing hot rolling mill. The following results were obtained; The optimal pack assembly condition and pack rolling process factor were produced. The effect that the difference in deformation resistance of cover material and core material in pack rolling has been considered. The S45C mild steel is the most suitable for the cover material. The cover material is subjected to the same rolling process as the core material when the initial core and total thickness ratio is 0.3. The reduction in pack rolling should be selected in the range of 20% to 25% to produce flat sheet. Tensile properties of the pack rolled sheet are isotropic in both RD and TD rolling direction which meet the requirements of the standard AMS4911.

Introduction

Titanium based alloy sheets were considered as suitable candidate materials for advanced aerospace structures and automotive structural components due to their high corrosion resistance, low density, high strength, and good formability [1, 2]. Among various titanium based alloys the two phase alpha-beta alloys constitute the group which has the most diverse applications especially in structural applications. Ti-6Al-4V alpha-beta titanium alloy is the most commonly used alloy accounting for about 80% of total titanium alloy production globally.

The manufacturing of Ti-6Al-4V alloy sheets, foil or thin structural sections are very difficult by elevated temperature processing. It has narrow processing window that the flow stress of Ti-6Al-4V alloy increases sharply when the alloy surface temperature decreases from 940℃ to 850℃[3]. Moreover, titanium and its alloys are hampered by the atmospheric contamination during elevated temperature processing.

One version of the protective encapsulation method known as pack rolling is commonly used in the titanium industry to produce thin sheets [4, 5]. Pack rolling is a process of encapsulating the reactive material such as titanium between two deformable protective cover plates followed by elevated temperature processing. The protective cans minimize heat losses, prevent oxidation and avoid contamination. A layer of inert parting or release agent is applied between the cover plates and work piece to facilitate easy removal of sheet or foil from the pack after rolling. Pack rolling eliminates the die chilling effects encountered in conventional bare rolling and has the ability to produce contamination free thin sheets and foils. And as conventional rolling mills can be used, the process is cost effective. For these good reasons, the process is used to produce large quantities of sheet and plate which are subsequently surface treated to remove oxidized layers.

Meanwhile, the factors of the pack rolling process such as pack material, pack design, parting agent etc. are very important because they have a significant impact on the shape of the core plate. Therefore, in the present work, the effect of thickness ratio of cover and core, number of core, cover material and reduction ratio on the shape of the core plate was investigated in addition to finding the optimal process condition in hot pack rolling directly, for the Ti-6Al-4V alloys. The evolution of thickness variation of the sheets after rolling in each process condition was studied using by contour mapping method. And also the mechanical property of sheet was examined at room temperature.

Experimental procedure

Ti-6Al-4V ingot with a diameter of 420mm and a height of 790mm was prepared using the vacuum arc re-melting (VAR) process from Toho titanium. The primary ingot breakdown is carried out in the beta phase field followed by secondary processing in the alpha + beta field to produce forged slab. Plate with dimension of W200 x L250 x T120 were cut from the forged slab and were hot-rolled on a two-high mill to make core plate with a thickness 5mm. Oxide scale of the core plate surface cleaned using a mixture of HF-HNO3. Mild steel plates were used as cover packing material. The boron based lubricant was used as a parting agent to prevent any kind of metallurgical bonding between titanium and mild steel at the processing temperature. Then, the coated plates were encapsulated in mild steel plates and sealed by e-beam welding. The packed assembly was heated to the rolling temperature of at 980℃ which is below the beta transus and held for 4hr before rolling. Hot rolling was carried out through multiple passes with intermittent annealing during every two pass at the rolling temperature. The rolled pack were then cooled with air after rolling. The pack was cut open and the rolled core titanium sheet was separated from the cover mild steel pack material. The core titanium sheet was subjected to secondary pickling. Tensile test specimens were cut along the rolling direction (RD) and transverse direction (TD) from the pack rolled thin plates and test were carried out with AMS 4911.

Results

The pack assembly designed in this study is summarized in Table 1. The amount of deformation imparted, thickness ratio of core and total before and after rolling and number of passes the pack assembly were shown in Table 2.

Case	Cover material	Ti-6Al-4V sheet dimension(mm)	Pack assembly dimension(mm)	No. of Core	Thickness before rolling [Core/total]
1	S45C	170 × 200 × 5	250 × 280 × 22	2	0.45
2	S45C	200 × 250 × 5	260 × 290 × 16.8	2	0.6
3	S45C	200 × 250 × 5	260 × 290 × 32.8	2	0.3
4	S45C	200 × 250 × 5	260 × 290 × 54	2	0.19
5	S45C	200 × 250 × 5	260 × 290 × 64	4	0.31

Table 1. Pack assembly and dimensional details

Case	No. of Passes	Reduction/Pass	Thickness of core(mm)		Thickness after rolling [Core/total]
			Initial	Final	
1	7	17	5	1.47	0.25
2	8	15	5	1.58	0.35
3-1	8	15	5	1.54	0.18
3-2	6	20	5	1.56	0.17
3-3	4	30	5	1.43	0.16
4	8	15	5	1.35	0.09
5	8	15	5	1.30	0.07

Table 2. Pass schedule and thickness reduction details

The pack rolling of Ti-6Al-4V plates were successfully performed in each cases. The final thicknesses of Ti-6Al-4V sheets obtained after rolling are summarized in Table 2. Sheet thickness of 1.3mm ~ 1.58mm was obtained by pack rolling.

In order to investigate the uniformity of the sheets deformation after rolling, the thickness in the width direction and the rolling direction was measured and the results are shown in Fig 1. In case of the thickness ratio of core and total before rolling is different as shown in Fig 1. (a)-(d), the thickness of the core sheets becomes thinner with increasing the thickness of the cover plate and some buckling seems to occur at 0.45 and 0.6 thickness ratio in the rolling direction. In case of different reduction ratio as shown in Fig 1. (e)-(g), a similar thickness of core sheets was obtained up to 20% reduction ratio, but the thickness significantly reduced when the reduction rate was increased to 30%. In case of different number of core sheets as shown in Fig 1. (h)-(i), the flatness of the core sheets was not good as increases of the number of core plates. The thickness of core sheet after rolling was almost 1.3mm which is most thin in number of core plate is 4. It seems that the thickness ratio of the cover materials and core materials is an important factor of rolling deformation characteristics.

The effect that the difference in deformation resistance of cover material and core material in pack rolling has been considered. If cover material and core material has the same deformation resistance, both materials have the same rolling reduction and elongation. On the other hand, the core material stretches more than the cover material, then buckling of the core material may occurs due to confinement. Conversely, when the core material is harder than the cover material, the reduction of the core material is smaller than that of the cover material. Since the elongation of the core material is smaller than that of the cover material, rolling is smooth but it is difficult to adjust sheet thickness of the core material. Fig. 2(a) shows the relationship between the thickness ratios of core and total thickness before and after rolling in the different type of the cover material. It means that under the S45C in core and the S45C in cover line, the core material is stretched more than the cover material and buckling of the core material is caused. The change in thickness ratio before and after rolling tends to decrease as the thickness ratio before rolling increases except in S45C cover material. The buckling areas of cover materials S45C and SS400 were investigated to find consistency of deformation resistance with core material and shown in Fig. 2(b). The right side of each line represents an area where buckling does not occur, which is larger than SS400 in the area of S45C. This result signified that S45C mild steel is the most suitable for the cover material.

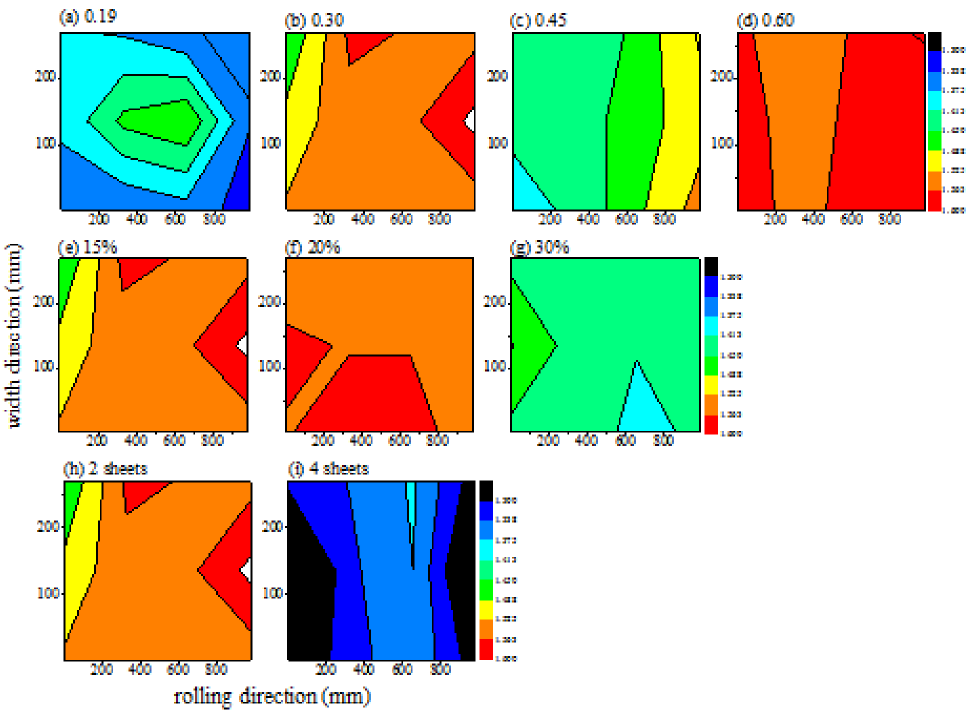

Figure 1. Thickness map of pack rolled Ti-6Al-4V. The parameter is core/total thickness ratio (a)-(d), reduction ratio (e)-(g) and number of core plate (h)-(i).

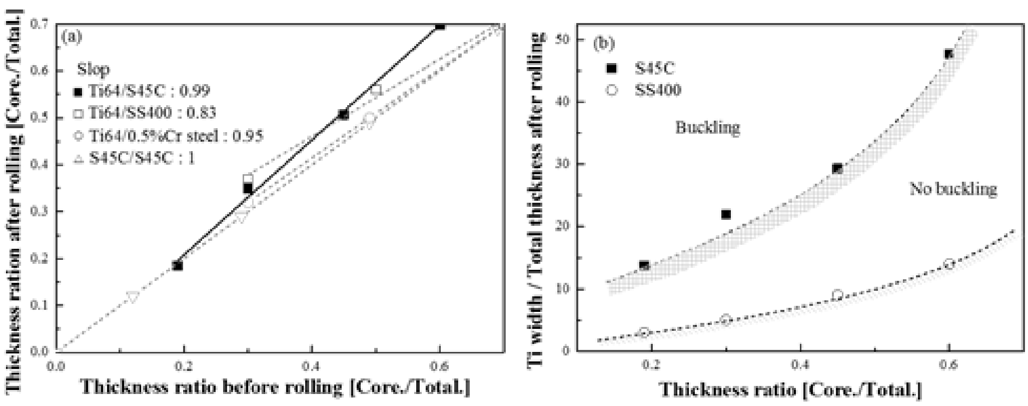

Figure 2. Effect of cover materials on the flatness of core material.

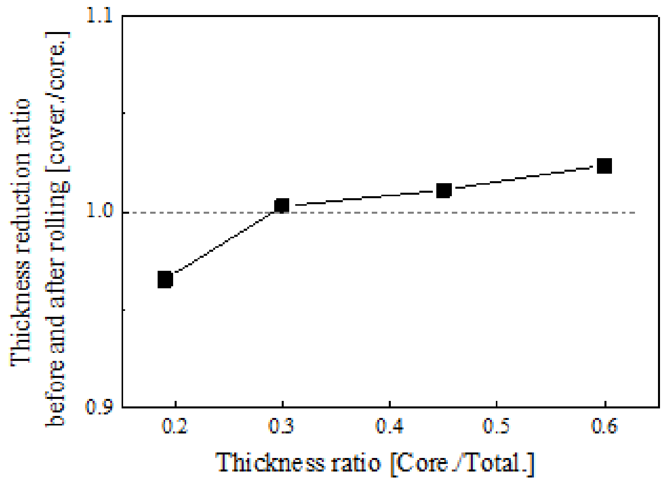

Figure 3. Rolling deformation behavior of pack assembly in various initial thickness ratio of cover material and core material.

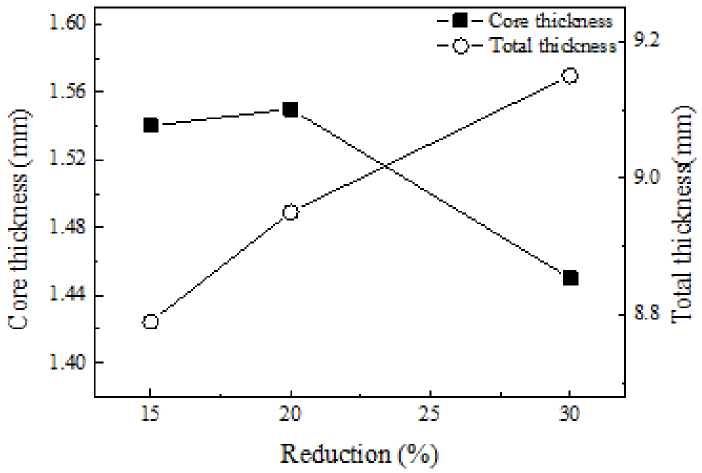

Figure 4. The relationship between reduction rate and the thickness reduction ratio of cover and core material.

The effect of thickness ratio of cover and core in the initial pack assembly on the reduction ratio of cover and core by rolling was investigated and the results are shown in Fig. 3. The thickness reduction ratio is defined as follows.

$$\alpha / \beta = [(t_1 - t_2) / t_1] / [(t_3 - t_4) / t_3]$$

where, t_1 and t_2 stands for the initial and after-rolled thickness of cover material, respectively, the thickness reduction ratio α of the cover material is represented by $(t_1\text{-}t_2) / t_1$. And the thickness of the initial core material is t_3, and the thickness after rolling is t_4, the ratio of reduction of the core material is expressed by $(t_3\text{-}t_4) / t_3$. The ratio of the reduction ratio, that is, $\alpha / \beta = [(t_1\text{-}t_2) / t_1] / (t_3\text{-}t_4) / t_3]$. It means that the thickness reduction rates α and β are the same when the thickness reduction ratio is 1. Namely, it suggest that the cover material is subjected to the same rolling process as the core material. The value α / β, in this research, is close to 1 when the initial core and total thickness ratio is 0.3, which means the most relevant thickness ratio for pack rolling.

Figure 4 shows the relationship between reduction rate and the thickness reduction ratio of cover and core material. As the reduction increases, the thickness variation of the core and cover material shows the opposite tendency. The thickness reduction of cover material is larger than that of the cover material at the reduction of less than 20%, and the thickness reduction of cover material is smaller than that of the cover material at the reduction of more than 25%. It suggest that the reduction in pack rolling should be selected in the range of 20% to 25%.

The change of temperature and pressure according to the number of passes in every case is shown in Fig. 5(a) and (b), respectively. The temperature and force increase with increasing the number of pass at 0.19 and 0.3 thickness ratio case. On the other hand, the temperature and force are stabilized with increasing the number of pass at 0.45 and 0.6 thickness ratio case. The reason is that if the thickness of the cove is thin, the load will increases because the plate temperature drops quickly. The reason is that the temperature of the pack assembly drops quickly, and therefore the rolling load is increased when the thickness of the cover material is thin. From these results, we found that the optimum condition for the production of the pack is 0.3 in thickness ratio of core and cover.

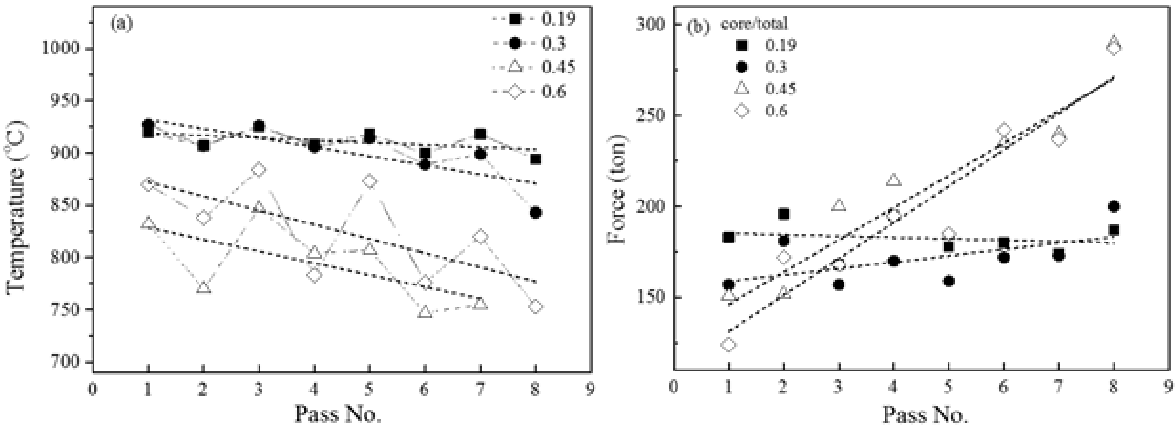

Figure 5. Temperature and rolling load in actual rolling

After annealing at 950℃ for 8hr, the room temperature mechanical properties of the titanium alloy sheet in the RD and TD in case 3-2 are shown in Table 3. It can be seen that the tensile properties of the pack rolled sheet are isotropic in both rolling direction. In addition, mechanical properties meet the requirements of the standard AMS4911.

Case 3-2	YS(MPa)	TS(MPa)	El(%)
RD	897	967	11
TD	866	920	10
AMS4911	869	920	8

Table 3. Mechanical property of pack rolled Ti-6Al-4V sheet in case 3-2.

Conclusions

1. Ti-6Al-4V alloy sheets of thickness 1.5mm have been successfully produced by hot pack rolling.
2. The pack rolling process factor of Ti-6Al-4V has been investigated as follows;

- The effect that the difference in deformation resistance of cover material and core material in pack rolling has been considered. The S45C mild steel is the most suitable for the cover material.
- The cover material is subjected to the same rolling process as the core material when the initial core and total thickness ratio is 0.3.
- The reduction in pack rolling should be selected in the range of 20% to 25% to produce flat sheet.
- Tensile properties of the pack rolled sheet are isotropic in both RD and TD rolling direction which meet the requirements of the standard AMS4911.

References

[1] M.R. Bache, W.J. Evans : Mat. Sci. Eng. A 319 (2001) 409.
[2] J.M. Liu, S.S. chou : Mat. Science and Technology 16 (2000) 1037.
[3] S.L. Semiatin : Advances in the science and technology of Titanium alloy processing 1997

[4] S.S Satheesh Kumar, S Sathiyanarayanan, T. Raghu : Metals Materials and Processes 19 (2007) 253
[5] J.W. Noble, H.S. Orr, F.R. Pomeo : U.S. Patent 3164844 (1965)