

Effect of rolling reduction rate on the forming of microstructures on the surface of 2024 aluminum alloy

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Abstract. The influence of the rolling reduction rate on the microstructure filling behaviour of the surface of 2024 aluminum alloy was investigated. We measured the forming height of the microstructure under different process parameters and used scanning electron microscopy to capture the surface topography and analysed the appearance of cracks and holes. In the process of rolling, the filling height of the 2024 aluminum alloy increases with the increase of the reduction rate, and the forming quality of the surface microstructure deteriorates with the increase of the reduction rate, and more microcracks and holes appear on the surface of the microstructure, and these defects are formed because of the introduction of additional tensile stress due to the uneven deformation.

1 Introduction

Relevant studies have shown that the microstructure has great advantages in drag reduction, superhydrophobicity and optical properties compared with the flat plate structure. The microstructure of the surface of the product can change the contact behavior and interaction between the surface of the material and the outside world, thereby improving some properties of the product surface [1] and optimizing the economic and ecological environmental protection of the product [2]. For example, the addition of microstructures to heat exchange devices can significantly increase the heat flux [3]. The characteristic size range of the surface microstructure is 0.01~1mm, which is called the mesoscale [4]. At present, microstructure processing technologies are mainly divided into three categories: additive manufacturing, subtractive manufacturing, and isometric manufacturing, and each of the three types of molding methods has its own advantages. Among them, roll forming technology has the characteristics of high production efficiency, small forming force, low cost, and is suitable for mass production, and has gradually become the most promising process in microstructure processing. During the rolling process, the contact between the roller and the material is approximately linear, which significantly reduces the forming load and reduces the effects of

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uneven material thickness and dust [5]. The refinement of surface features not only affects the quality of the product under the process conditions and conditions, but also has a direct impact on the forming quality of the material [6]. The surface quality of microformed parts is also critical for their functional performance, for example, the poor surface quality of microformed metal bipolar plates leads to high contact resistance and low corrosion resistance [7]. Yamamoto et al. studied the roll forming process of the surface microstructure of small metal shafts, and analyzed the effects of the amount of mold indentation and the convex characteristics of the mold surface on the micro-roll forming performance [8-10]. In this paper, the 2024 aluminum alloy is taken as the research object, and the influence of the reduction rate on the microstructure filling behavior of the 2024 aluminum alloy roll forming surface is discussed.

2 Experimental

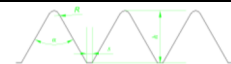
In this experiment, 2024 aluminum alloy was selected after solution treatment and then naturally aged. The material wire of the receiving state is cut into a pattern of 100mm×10mm, and the average thickness of the pattern is 1.27mm, and the rolling is carried out by the mold with array microstructure, and the main technical parameters of the rolling device are shown in Table 1. Set the initial spacing of the upper and lower rollers is the plate thickness of the sample, adopt 20%, 40%, 60% and 80% of the plate thickness respectively as the pressing rate to carry out the roller pressing experiment, the upper roller is the smooth roller, the lower roller is the roller with triangular microstructure, the design of the microstructure is shown in Table 2, the speed of the upper and lower rollers are all 5mm/s, and the roll surface of the upper and lower rollers does not add lubricant. In this experiment, a laser confocal microscope with model OLS3000 was used to measure the forming height, a Quanta 200FEG and Zeiss field emission scanning electron microscope equipment were used to obtain the topological characteristics of the sample, and a metallographic microscope with model OLYMPUS-GX71 was used to observe the microstructure and microstructure characteristics of the sample after forming.

Table 1 Parameters of the rolling device

Maximum roll pressure/KN	Maximum Torque /(N·m)	Roll diameter /mm	Maximum roll width /mm	Rated speed / (r/min)
200	500	110	80	37

Table 2 Key dimensions of triangular microstructures

$h/\mu\text{m}$	$s/\mu\text{m}$	$\alpha/^\circ$	$R/\mu\text{m}$
200	20	60	20

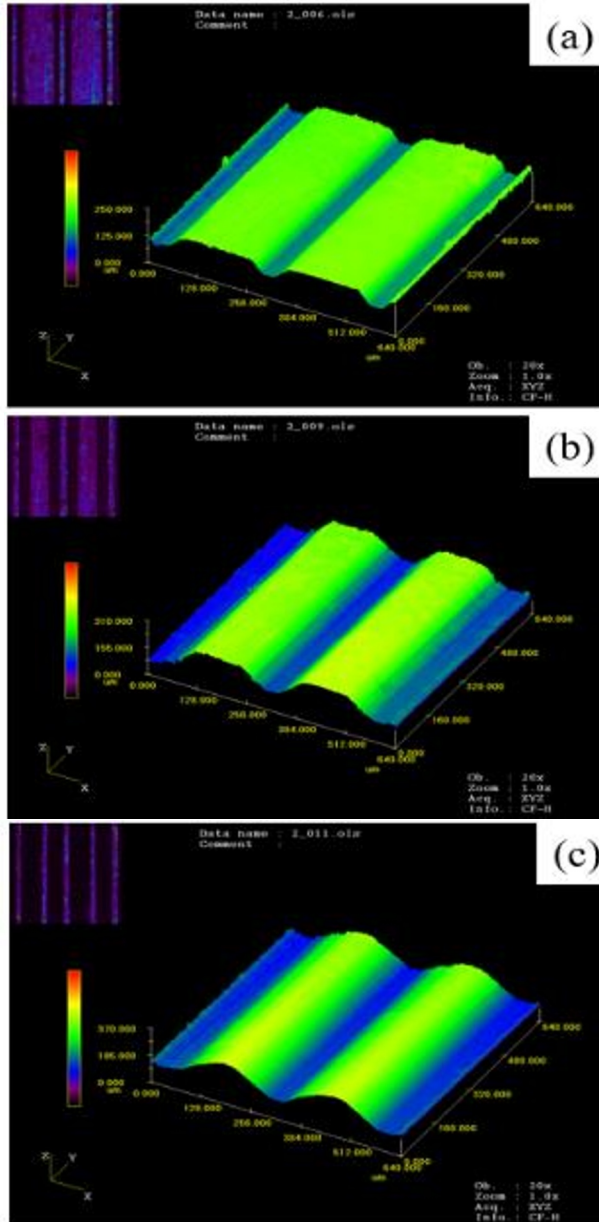


3 Results and discussion

3.1 Effect of reduction rate on the forming height of array microstructures

The three-dimensional profile (as shown in Fig. 1) and cross-section profile (as shown in Fig. 2) of the array microstructure were observed by laser confocal and the height of the four microstructure peaks was measured, and the average value was taken as the feature height of the array microstructure. The feature heights of the array microstructure at different reduction rates are shown in Fig. 3. As can be seen from the figure, the height of the microstructure features increases significantly with the increase of the reduction rate. This is mainly due to

the fact that with the increase of the reduction rate, the roll spacing decreases, and the local pressure increases, so that the material is extruded into the mold groove, and then the height of the microstructure feature is increased. When the reduction rate is large, the height of the microstructure changes very little due to the influence of the processing depth of the mold, and the microstructure topography is close to the designed triangular shape. It can be found from Fig. 2 that when the small pressure rate is rolled, the groove structure appears at the top of the microstructure, and the whole microstructure presents a platform shape, and when the high pressure rate is rolled, the top of the microstructure is convex. This is due to the different deformation behaviors of different parts of the material, resulting in uneven friction and roll pressure.



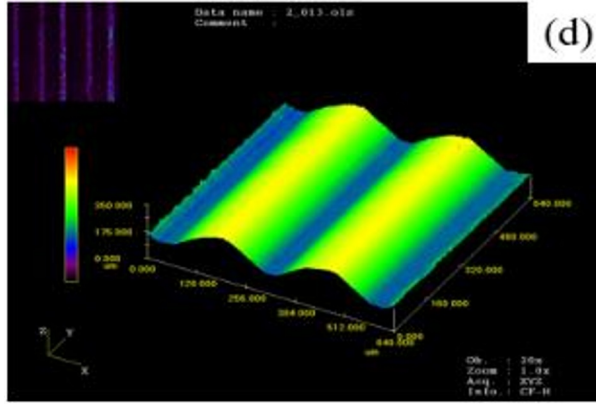


Fig. 1. Three-dimensional contour of the array microstructure: (a) 20%, (b)40%, (c) 60%, (d) 80%

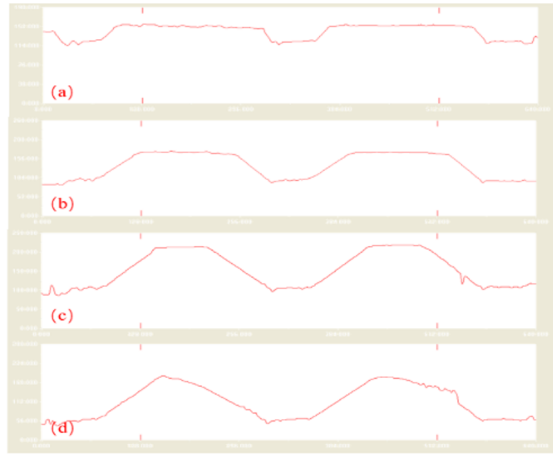


Fig.2. Cross-sectional profile of microstructure at different reduction rates: (a) 20%, (b) 40%, (c) 60%, (d) 80%

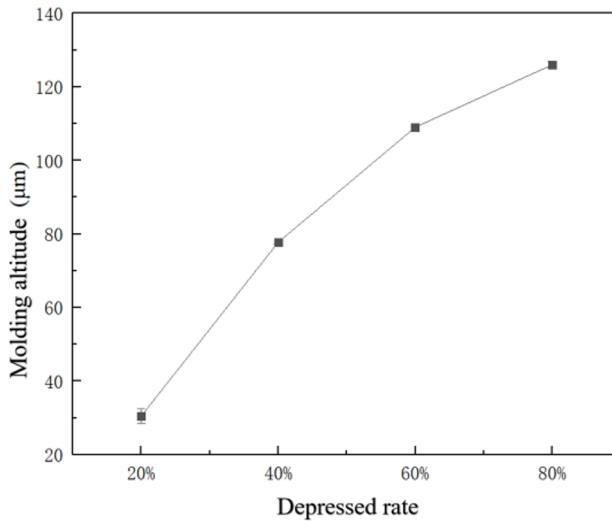


Fig.3. The characteristic height of the microstructure at different roll gaps

3.2 Effect of reduction rate on the surface quality of microstructures

In order to analyze the effect of the surface quality of the array microstructure with different reduction rates, the surface of the solid-solution 2024 aluminum alloy array microstructure was characterized by SEM. Fig. 4 shows the surface topography of the microstructure at 20%, 40%, and 60% reduction, respectively. When the reduction rate is 20%, some inconspicuous cracks appear on the surface, and the surface on both sides is not flat in comparison. With the increase of the reduction rate, the plateau area above the microstructure gradually becomes smaller, and the surface morphology of the microstructure becomes worse, and when the reduction rate is 80%, obvious cracks appear at the top of the microstructure.

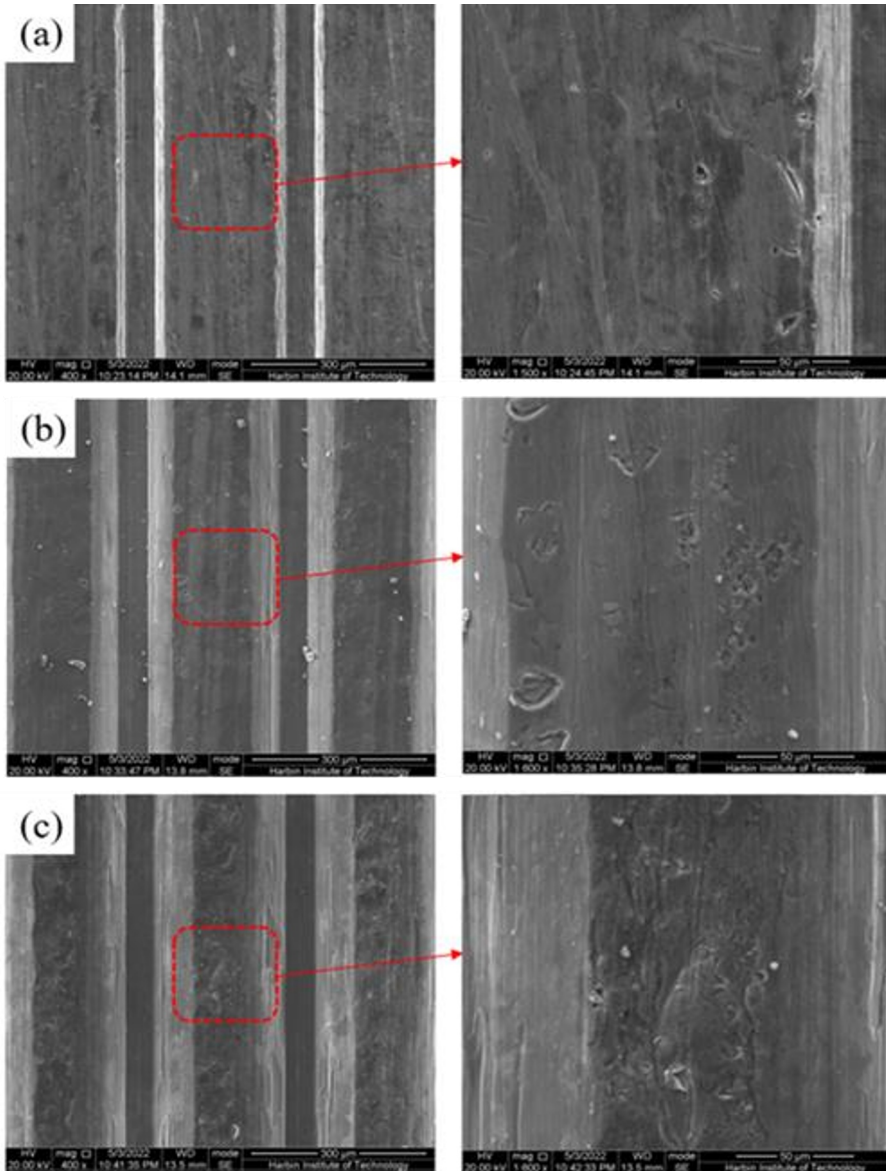


Fig.4 Surface morphology of microstructure with different pressure rates: (a) 20% (b) 40% (c) 60%

Cracks on the surface of the microstructure are caused by the introduction of additional tensile stresses due to inconsistent local plastic deformations. In the roll forming process, the stress state of the upper surface is shown in Fig. 5. Point P_1 is subjected to compressive stress and frictional tensile stress from the die, respectively, and the frictional force f_1 along the rolling direction is brought by the lower roll with a microstructure, f_1 can promote the forward flow of the plate and the material. P_2 point because it is deformed by extrusion, does not contact with the die, belongs to free deformation, so the friction force f_1 of P_1 point is greater than the friction force f_1 of P_2 point, the material flow velocity V_{RD} along the rolling direction gradually decreases from P_1 point to P_2 point, and f_2 is the friction force that is on the surface of the microstructure die and perpendicular to f_1 , points to the top of the microstructure along the microstructure wall, can limit the material to fill upward, so the material flow velocity V_{ND} gradually increases from P_1 point to P_2 point. The combined action of these two forces results in a difference in the velocity of the material flow at points P_1 and P_2 in the ND and RD directions, which in turn creates additional tensile stresses. When the additional tensile stress exceeds the tensile strength of the material, cracks occur on the surface.

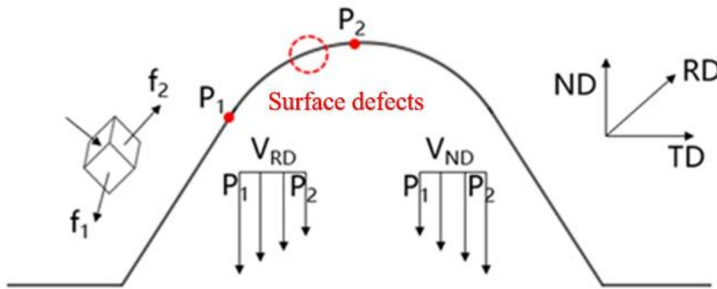


Fig.5 Schematic diagram of the local stress state in the rolling process

3.3 Effect of reduction rate on microstructure microstructure

In order to study the way in which the 2024 aluminum alloy is filled with a mold during the rolling process, a metallurgical microscope was used to observe the grain patterns in the thickness direction of the three reduction rate patterns. Observing Figure 6, it can be seen that the deformation of the material mainly occurs at the bottom arc of the microstructure, where the grain is compressed, forcing the grain to elongate in the TD direction, and the degree of deformation of the metal decreases with the distance from the arc. As the amount of reduction increases, the grains in this section will flow upwards along the wall of the mold to form streamlines, as shown in Fig. 6(b)(c), and the grains flowing along the wall are further elongated by the friction of the wall. The grain of these two parts is deformed in harmony, so that the microstructure is highly raised. By comparing the grains at the middle protrusion and the arc of the microstructure, it can be found that the grain deformation at the middle protrusion is small, and even the grain size does not change much from the initial grain at the small pressure rate, and most of the grains are equiaxed grains. It can be inferred that when this part of the grain is subjected to external pressure, it fills upwards into the inside of the mold, resulting in a large rigid displacement and a small local grain deformation. Therefore, it can be considered that in the whole deformation process, most of the deformation is in contact with the mold part, and the contact pressure induces plastic deformation, and with the increase of the reduction rate, the deformation affected area becomes larger, and the grains involved in the deformation increase.

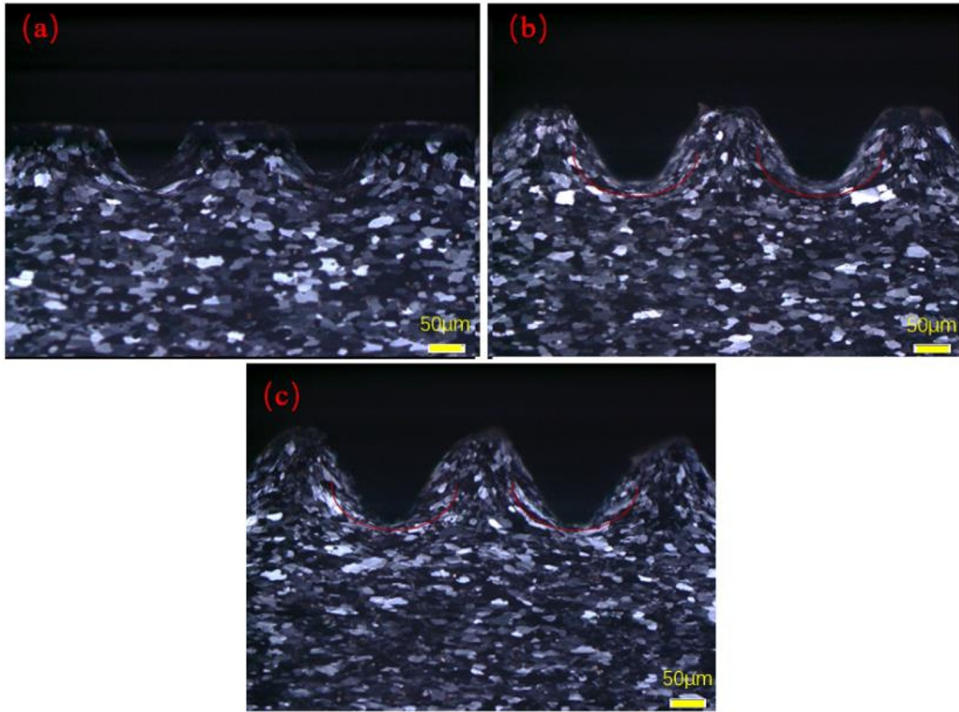


Fig. 6 Microstructures with different reduction rates (a) 40% (b) 60% (c) 80%

4 Conclusions

1. For the 2024 aluminum alloy material roll forming, the forming height of the microstructure increases with the increase of the amount of reduction, the reduction rate is small, the microstructure presents a platform shape, and when the reduction rate is large, the top of the microstructure is convex.

2. The surface quality of 2024 aluminum alloy after forming deteriorates with the increase of the reduction rate, when the reduction rate is 20%, some inconspicuous cracks appear on the surface, and when the reduction rate is 80%, obvious cracks appear at the top of the microstructure. This is due to the introduction of additional tensile stresses due to inconsistent local plastic deformations.

3. In the process of 2024 aluminum alloy roll forming, the deformation of the material mainly occurs at the arc at the bottom edge of the microstructure, and the grain in this part is compressed, forcing the grain to elongate in the TD direction, and the deformation degree of the metal decreases with the distance from the arc. With the increase of the reduction rate, the deformation affected area becomes larger, and the grains involved in the deformation increase.

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