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ARTICLE

Microstructure Characteristics of Serrated Groove Formed by Inner Spinning on the High Temperature Alloy Tube

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Abstract: A large-diameter thin-walled high temperature alloy tube with serrated groove was prepared by inner spinning method, whose blank was welded up, and the micro-hardness and microstructure characteristics of the serrated groove in the tube were investigated. The results show that the welding results in coarse and uneven dendrites in the as-welded joint, which leads to larger difference in micro-hardness between the as-welded joint and the outer zone of the as-welded joint. Both the original grains of the outer of the welded joint zone and the dendrites of the as-welded joint are refined by the inner spinning on the serrated groove. The micro-mechanical property unevenness of the serrated groove is significantly improved by severe plastic deformation.

Key words: serrated groove; inner spinning; high temperature alloy tube; microstructure characteristics; micro-hardness

High temperature alloy tubular thin-walled parts are usually used as the shells of container and other equipment which serve in high-temperature environment. They are processed by forming some grooves on the tubular blank. Sometimes the tube has to be welded by a rolled metal plate due to its large diameter. And then the grooves with different shapes and depths are processed in the tube by plastic forming.

Bulging is often adopted to form the grooves, but large and complex molds and equipment are needed [1-3]. This will lead to higher production costs and longer producing period. Spinning is a metal forming technique which saves material and reduces energy consuming. Because of its regional progressive forming process, spinning outputs less working force and small machine tonnage is needed. The dies for spinning are simplified by replacing the cavity block with the rollers. Therefore the spinning technique is suitable for multi-species and small batch production, and it has been widely used[4,5].

There are two main kinds of cylinder spinning: one is power spinning with tubular blank, and the other is drawing spinning with sheet blank. Jiang et al[6,7] spun the thin-walled tubular part with longitudinal inner ribs using a multi-pass spinning roller path and a ball mandrel. It was found that grain refinement can be caused by severe plastic deformation; a larger ball size will contribute to the formability of the inner ribs as well as the metal flow of the workpiece surface. The deformation characteristics and spinning forces during tube spinning using different roller distribution modes were investigated by Xu et al [8]. They found that the variation of spinning forces causes the mandrel to deviate from the neutral axis, and it was proposed to perform the stagger spinning with non-uniformly distributed three rollers so as to achieve the balance of the mandrel. Huang et al [9] spun a neck part of the tube end at an elevated temperature which is used as a high pressure CO_2 vessel. The thickness distribution of the tube formed by a curved path was more uniform than that of the tube formed by a straight path.

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The effect of cold thinning spinning on the performance of Ni-based alloy tube was evaluated by Li et al [10] through metallographic test, tensile test and electrochemical corrosion test. The experiment results showed that highly-refined crystalline grains appear on the surface of extruded blanks with an upsurge of the tensile strength and a decrease of elongation and corrosion resistance after thinning spinning. Ahmed et al [11] proposed a new sheet metal deep spinning process with roller set aided and blank-holder, aiming to suppress the wrinkling formation in the deformation zone. The limiting spinning ratios (blank to mandrel diameters ratios) increased from 1.76 using the conventional spinning to 2.40 using the new method. Li et al [12] pointed out that the roller path combined with the convex-concave curve could contribute to the shape precision through the simulation of sheet metal die-less spinning. Essa and Hartley [13] investigated the effect of roller path on the wall thickness thinning in dual pass cup spinning by simulation.

The deformation behavior and grain evolution of tubular and sheet blanks during tube spinning were reported by the above investigations. The main focus is on the integral formability and geometric performance, but the welded joint is rarely associated with which may be the weakest link. Yuan et al[14,15] firstly obtained the large diameter thin-walled tube from an aluminum alloy plate using friction stir welding (FSW). The tube was then subjected to thinning spinning and heat treatment to promote grain refinement. After that, the mechanical properties and plastic forming ability of the tube and welded joint were enhanced, which can be considered as a tube blank making process. The shape of the welded joint didn't change much, and its deformation behavior during spinning was not taken into consideration.

According to the close relationship between the microstructure and macroscopic mechanical properties of the workpiece, a serrated groove was formed on the high temperature alloy tube by spinning in this study, and the deformation behavior and microstructure characteristics of the serrated groove were investigated.

1 Spinning Experiment

The section profile of the serrated groove on the FSW tube is shown in Fig.1. A wavy roller path was designed due to the complex shape of the serrated groove with the generic roller. It is very detrimental to controlling the shape and wall thickness of the inner spinning. Therefore a profiling roller whose profile is processed into the corresponding serrated shape as shown in Fig.2 is adopted and only a foolproof roller path expressed as a line is needed.

The serrated groove spinning in this experiment is an inner one, and the outer mold is designed. In order to facilitate the die stripping, the part with the serrated cavity in the mold is departed into two modules. The three parts-base, the upper and lower semicircular modules make up the whole die for the serrated groove inner spinning, which is shown in Fig.3.

The assembly of the modules and tools is illustrated in Fig.4. The spinning experiment is carried out on the PS-CNCSXY 5 spinning machine with the rotation velocity of 300 r/min and a radial feed of 0.01 mm/r. The material of the tube blank is Hast.X high temperature alloy and the diameter and thickness of it are 355 mm and 1.57 mm, respectively. The feed rate of the roller is 0.01 mm/r. The chemical composition of the high temperature alloy tube blank is shown in Table 1.

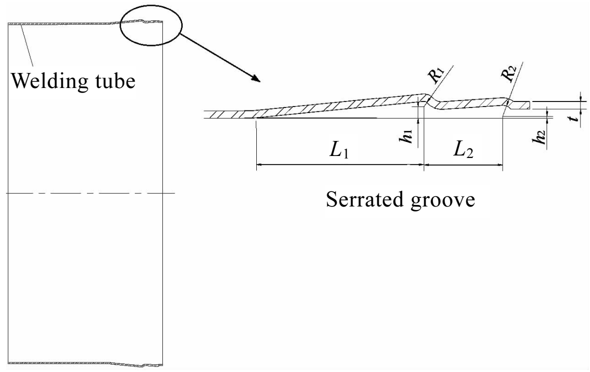

Fig.1 Section profile of the serrated groove

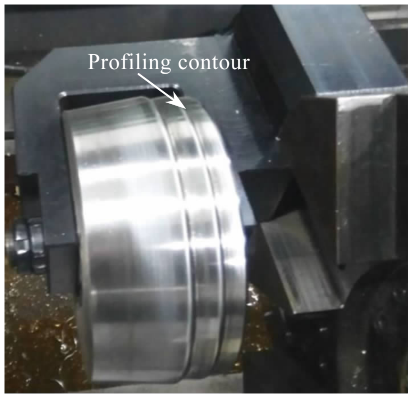

Fig.2 Profiling roller

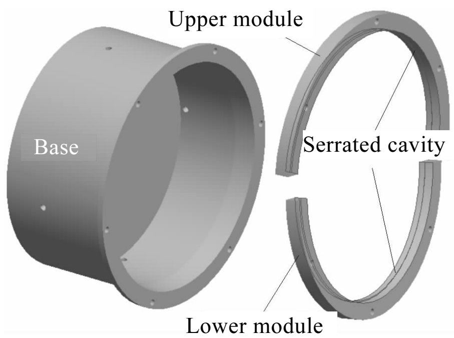

Fig.3 Serrated groove inner spinning dies

Table 1 Chemical composition of the high temperature alloy (wt%)

Al	Cr	Nb	Mo	W	Co	Si	Mn	P	Fe	Ni	Cu
0.48	21.43	0.12	9.25	0.52	1.28	0.42	0.63	0.028	19.1	46.5	0.06

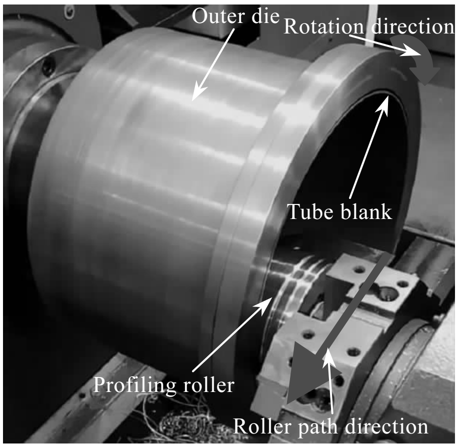

Fig.4 Assembly diagram of serrated groove spinning

The spun part is exhibited in Fig.5, and the contour accuracy is examined by the templet obtained through machining. The wall thickness distribution of the serrated groove is also shown in Fig.5. And this proves that the tube with precise serrated groove can be spun. The thinnest wall appears on the position with the biggest radius of the tube due to the largest compressing distance.

2 Hardness Distribution of the Spun Serrated Groove

In order to reveal the micro-mechanism of the mechanical properties of the spun workpiece, the Vickers micro-hardness (under a load of 200 g for 10 s) of the serrated groove was investigated. The spun serrated grooves on the workpiece inside and outside the welded joint zone were cut axially and made into two specimens which display their cross section for subsequent analysis. In order to make a comparison, the undeformed workpiece inside and outside the welded joint zone is also inlayed into the specimens (shown in Fig.6) for the investigation.

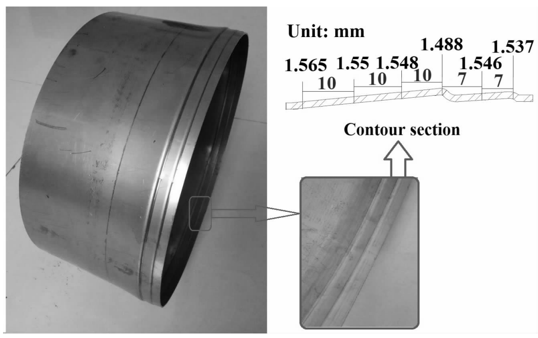

Fig.5 Spun part and its wall thickness distribution

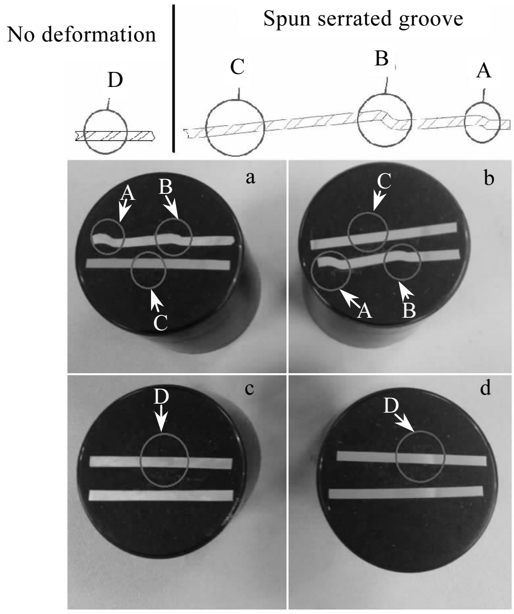

Fig.6 Inlayed specimens of serrated grooves on (a) and outside (b) the welded joint; undeformed parts inside (c) and outside (d) the welded joint zone

Three points in area A, B, C and D of both as-welded joint and outer region of welded joint specimens are randomly selected and measured for micro-hardness, as shown in Fig.6. The three test values in the same area are averaged and taken as the micro-hardness of this area. Fig.7 shows the micro-hardness distributions of the spun serrated groove inside and outside the welded joint zone. For the undeformed part (area D) on the tube, the as-welded joint has a higher micro-hardness than the outer zone of welded joint. There is an entire hardness enhancement in two zones of area C in contrast with in the area D. Both areas “B” have their own maximum micro-hardness value of 3230 MPa (as-welded joint) and 3170 MPa (outer zone of welded joint). The difference in micro-hardness value between the as-welded joint and the outer zone of welded joint decreases after the inner spinning, and the least difference emerges on the area B where the largest plastic deformation occurs (because the largest spinning feed and thinnest wall thickness of the serrated groove are at area B). There is a second maximum micro-hardness value at area A for both as-welded joint and outer zone of welded joint. However, the micro-hardness of the as-welded joint decreases compared with the one outside the welded joint, which has the second largest deformation in the four areas. Micro-hardness is closely related to the microstructure. Thence, the microstructure characteristics analysis was carried out.

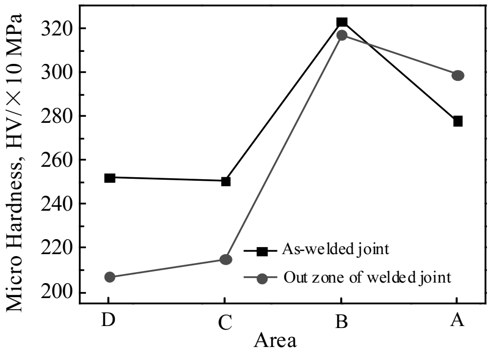

Fig.7 Micro-hardness distributions of the spun serrated groove

3 Microstructure Characteristics of the Spun Serrated Groove

The specimens are polished with the sandpaper (from 150# to 2000#) and polishing paste (P2.5 μm and P1.5 μm) firstly, and then corroded with corrosive liquid ($CuSO_4$+HCl), so as to analyze the microstructure characteristics of the spun serrated groove. Thence the microstructure of the specimens can be observed through the optical microscope (OM), as shown in Fig.8 (as-welded joint) and Fig.9 (outer zone of the welded joint). It can be found from Fig.8, the microstructure of the as-welded joint exhibits a coarse and inhomogeneous dendrite morphology caused by no-deformation welding (Fig.8d) or small

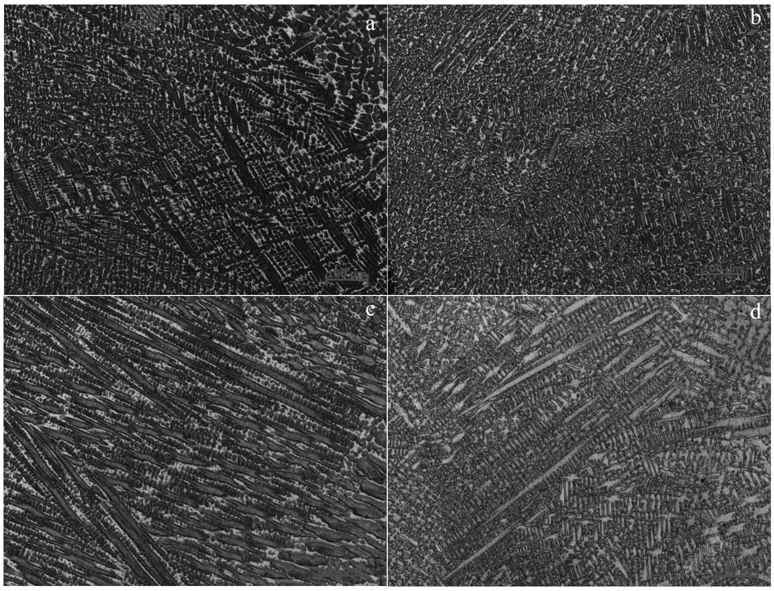

Fig.8 Microstructures of the as-welded joint: (a) area A, (b) area B, (c) area C, and (d) area D

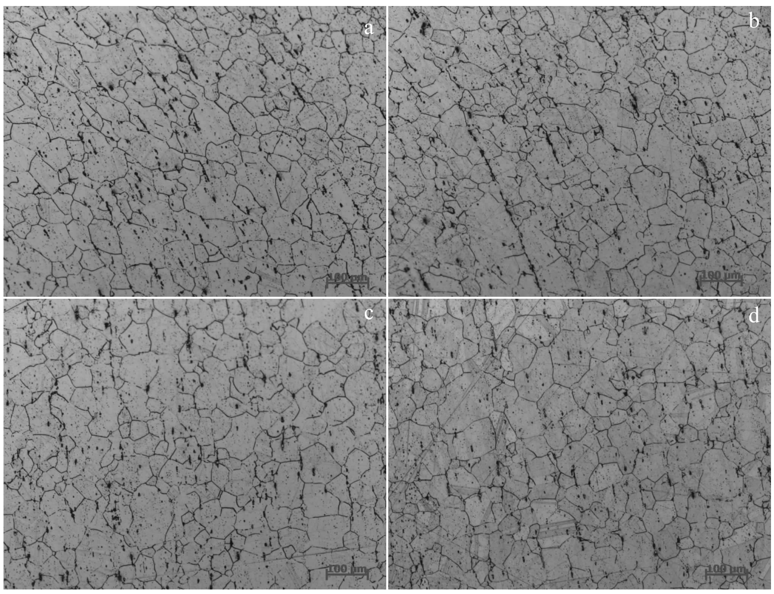

Fig.9 Microstructures of the outer zone of the welded joint: (a) area A, (b) area B, (c) area C, and (d) area D

deformation welding (Fig.8c). The coarse dendrite becomes finer with the increase in the deformation, and gets the finest at area B (Fig.8b), where the largest spinning compression occurs.

Fig.9 illustrates the microstructure characteristics of the outer zone of welded joint, which presents the grains with boundaries rather than dendrites. The difference in microstructure characteristics reflects why the micro-hardness of as-welded joint is higher than that of the outer zone. According to GB/T6394-2002, the grain size grade of area A (Fig.9a) and area B (Fig.9b) is level 6, and that of area C (Fig.9c) and area D (Fig.9d) is level 5. This means that the grain size also decreases with the increase of the deformation. It can be understood that the micro-hardness of the outer zone of welded joint is significantly increased and becomes closer to that of the as-welded joint. This is because the grain size is reduced due to the largest deformation at area B.

4 Conclusions

1) Large-diameter thin-walled high temperature alloy tube with serrated groove is produced using a novel process of inner spinning.

2) Not only the original grains of the outer zone of the welded joint but also the coarse and uneven dendrites of the as-welded joint are refined after inner spinning on the serrated groove.

3) The maximum micro-hardness and the finest grains appear in the area B where the largest deformation occurs on the serrated groove. The difference in micro-hardness between the as-welded joint and outer zone of welded joint reaches a maximum in the non-deformation region of the tube, which decreases when the spinning deformation gets larger.

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高温合金筒内旋压锯齿形沟槽微观组织特征

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摘 要：采用焊接板预制坯以及内旋压的方法制造了一种带壁锯齿槽的大直径薄高温合金筒。研究了筒内锯齿槽的显微硬度和显微组织特征。坯料的焊接导致了接头处微观组织为粗大且不均匀的树枝状支晶，这致使焊接接头与其外区域之间的显微硬度差异较大。内旋压促使锯齿槽上焊接接头区外的初始晶粒和焊接接头处的树枝状支晶都发生细化。锯齿槽的微观力学性能不均匀性因剧烈的塑性变形而明显得到改善。

关键词：锯齿形沟槽；内旋压；高温合金筒；微观组织特征；显微硬度

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