An EBSD study of Texture Variation along Pilger Reduced Titanium Alloy Tubes.

Harvinder Singh Ubhi[1, a], Andrew Houghton[2, b] and Janardhan Saithala[3, c]

[1] Oxford Instruments, Halifax Road, High Wycombe, HP12 3SE, UK

[2] Promet Consulting Ltd, Plymouth, UK

[3] Fine Tubes Ltd, Estover Works, Plymouth, Devon, PL6 7LG, UK

[a]singh.ubhi@oxinst.com, [b]info@prometconsulting.co.uk, [c]JSaithala@fine-tubes.co.uk

Keywords: Titanium, EBSD, micro-textures, Kearn's f-factors.

Abstract. This study investigates the changes in radial micro-texture via Kearn's f-factors during single cold pilger reduction of a titanium Ti-3-2.5 alloy as a result of strain path changes from tooling modifications. EBSD results confirm that the texture intensity as well as the radial f-factors can be increased by modifications of pilgering tooling. In addition a switch between the secondary prism planes which lie normal to the pilger direction in the starting tube to primary prism planes after pilgering has been observed.

Background

For many years the aerospace industry has used hydraulic power to drive actuators that constantly adjust the aircraft control surfaces. Operating under high hydraulic pressure, the tubing used in the system requires high strength to weight and good impulse fatigue strength - particularly with respect to hoop strength. These reasons led the aerospace industry to adopt the Ti-3-2.5 alloy as the standard for titanium hydraulic tubing [1-3]. This material is a near alpha alloy which contains 3% aluminum and 2.5% vanadium. When cold worked the alpha close pack hexagonal structure can slip predominantly on the basal, prism and pyramidal planes. All three planes are said to slip in one direction that is normal to the basal pole. This tends to rotate the basal poles towards the direction of the resolved force that is causing the strain to occur until twinning is the only means of deformation possible.

If the basal poles become aligned in the direction corresponding to the principle stresses applied in service it will be difficult for the critical resolved shear stress of any of the slip planes to be exceeded. Hence the tube will be texture strengthened. By altering the start sizes and strain paths during fabrication a texture strengthened tube can be produced.

The cold pilgering process is used to reduce both the tube outside diameter and the tube wall thickness. The area reduction rate of the cold pilger process usually exceeds 50 percent and can range as high as 93 percent. The pilger princliple uses two rolls, opposite each other, which roll over the cold tubing material [4]. Each roll or die is equipped with a groove that perfoms the actual work, or reshaping of the tube outside diameter. As the dies reduce the tube outside diameter the tube wall is reduced simultaneously. This wall reduction is accomplished by the use of a mandrel. The mandrel profile allows for the reduction of the wall and inside diameter of the tube. The tube is also turned between each rolling movement and incrimentally fed into the machine. A roughly conical shaped transition is therefore formed between the ingoing outer diameter and the outgoing outer diameter with the tube wall being reduced continuously along the length of the cone. Both the outer and inner longitudinal profiles are produced by curved profiles on the roll and inner mandrel. The mandrel is held stationary in the longitunial direction while the rolls move backward Therefore, although the ingoing and outgoing sizes may be kept the same, it is possible to alter the strain path by changing the curves of the longitudinal profiles on the rolls (often refered to as dies) and mandrels.

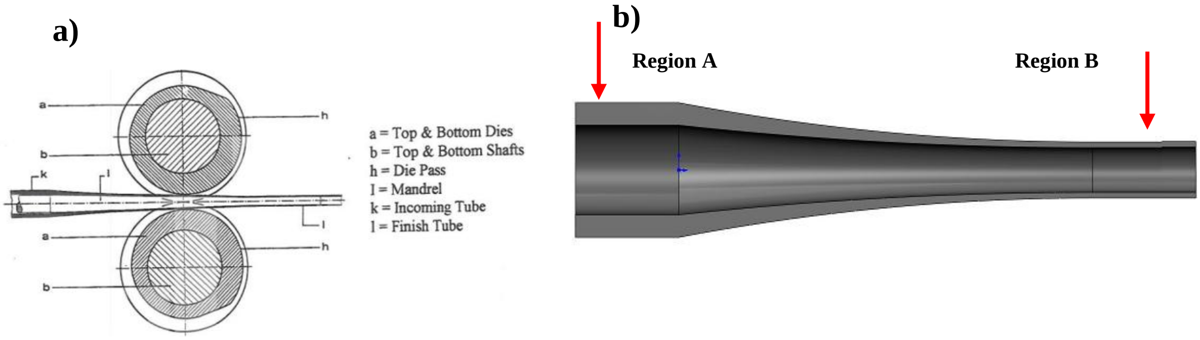

Fig 1: a) Side view of the Pilger principle [4] b) Enlarged conical shape of cone

For instance the wall reduction can be high at the early part of the transition and low at the end or vice versa. This paper makes a comparison of what happens to the texture when the same overal reduction is used for these two extremes. For the purposes of this article the situation where the wall reduction is low at the start of the reduction and high at the end of the reduction is termed 'texture maximised', whereas the opposite condition is called ‘texture minimised‘. Consistancy of texture through the wall thickness may also be important in reducing residual stresses in the tube and in minimising stresses in service because the elastic modulus varies with basal pole alignment.

Material and Experimental

The tubes investigated were made from Ti alloy 3Al 2.5V, they were manufactured via hot extrusion and cold pilgering. They were annealed at 750^{o}C before being cold pilgered for this investigation and they were stress relieved at 530^{o}C for approximately 2 hours prior to EBSD examination. Specimens were extracted from two regions either side of the reduced tube as shown in Figure 2 (b), mounted in conductive Bakelite and polished mechanically for EBSD examination. The final polish was carried out using vibratory polishes using a mixture of 5:2 colloidal silica, hydrogen peroxide mixture. EBSD examination was conducted using a FEGSEM and OI-HKL EBSD Nordlys detector and AZtec Software.

'Q' factor

A convenient measure of the relative amount of wall reduction to diameter reduction is called the Q factor. This is simply the ratio of the wall strain to diameter strain for that part of the reduction being considered. For the purposes of this paper the reduction has been divided into forty increments and the Q factor calculated for each increment. The forward movement of the transition cone, which commences as soon as the reduction starts, is taken into account. It follows from the above that comparing the incremental Q factors between the two sets of conditions described above i.e. the ‘Texture maximised' condition and the ‘without texture‘ condition will partially define the strain path in terms of the likely affect on the texture development

Results and Discussion

Typical SEM back-scattered images from the starting and pilgered tube sections tube are shown in Figure 2, indicating that the equiaxed starting alpha structure gets reduced to a deformed non-uniform grain structure. Some alpha phase is present in the alloy. EBSD maps from these sections are shown in Figure 3, these clearly show the change in microstructure during pilgering. EBSD contoured pole figures before and after pilgering are shown in Figure 4. These clearly show the development of a prism fibre texture after pilgering. This also has the effect of switching the secondary prism intensity normal to the tube direction in the starting material to the primary prism after reduction. Figures 2, 3, and 4 only relate to the “texture maximized” sample because visually there is little difference to be seen. The (0001) Kearns f-factors are given in Table 1 for the two tubes examined. It is clear from this table that f-factors increase after reduction and that there are differences between the two samples. A summary of the pole figure intensities and grain sizes are

also given in Table 1. Pole figure intensities increase significantly with reduction as does the mean grain size. It can be seen from table 1 that the 'Texture maximized" profiles have resulted in a relatively greater increase in radial texture than the 'Texture minimized" samples with a corresponding drop in the tangential or circumferencial texture. This was to be expected from established theory, but it is none the less interesting that the theory holds good even when the percent reductions are quite high. The overall percent reduction was in the region of 78%. There was very little relative difference with the increase in texture intensity. There could be a difference in through wall variation and this is to be investigated since it is likely that it will be less on the "texture maximized" samples. This could have a bearing on fatigue strength since texture orientation affects the elastic modulus.
The EBSD results also showed that the unit cells had rotated around the basal poles and this was again similar for both profile sets.

Conclusions

EBSD observations have confirmed that texture development can be manipulated in this product by altering the strain path.

This work aids the process of predicting textures ahead of tooling manufacture and this will be enhanced further by correlating results with observed strain paths produced by non-linear finite element analysis.

References

[1] W.F Spurr, W.E Quist, The effects of crystallographic texture on the mechanical and fracture properties of Ti-3Al-2.5V hydraulic tubing. Proceedings of the SAE G-3 committee symposium. Jan 24, 1973, Orlando, USA.

[2] T.W Rees, The development and control of crystallographic texture in 3 Al-2.5V titanium alloy tubing. Proceedings of the SAE G3 committee symposium. Jan 24, 1973, Orlando, USA.

[3] C.J Shaver, Quality requirements for Ti-3Al-2.5V annealed and cold worked hydraulic tubing,Proceedings of the SAE G3 committee symposium. Jan 24, 1973, Orlando, USA.

[4] Glen Stapleton, Cold Pilger Technology, Mannesmann Demag Meer.

Table 1. Summary of Kearn's f-factors, pole figure intensities and grain sizes for the two tubes processed as shown in Fig 3

	Texture minimised		Texture maximised	
Sample	exit	entry	exit	entry
f-factors (0001)				
Fx tangential	0.405	0.465	0.360	0.460
Fy radial	0.558	0.493	0.605	0.490
Fz longitudinal	0.037	0.042	0.034	0.050
Pf intensity	10.30	4.4	10.10	6.07
Mean Grain size (µm)	0.6	4.4	0.6	4

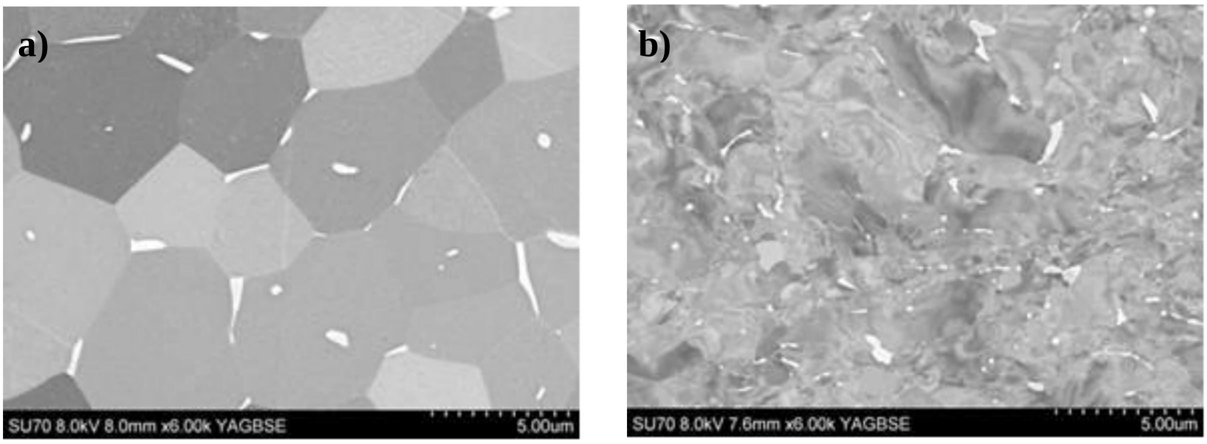

Figure 2: SEM back-scattered images a) of the starting tube and b) after reduction

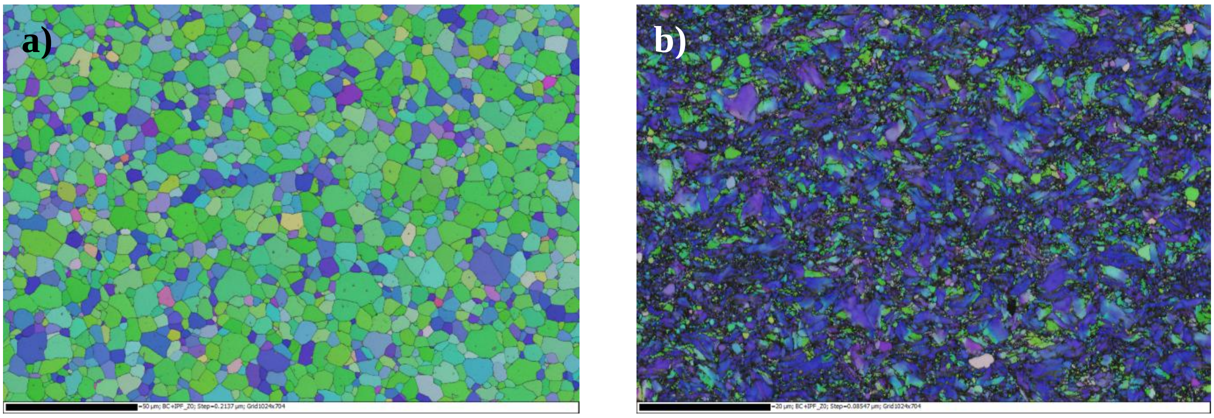

Figure 3. EBSD IPF Z coloured maps a) starting tube and b) after reduction.

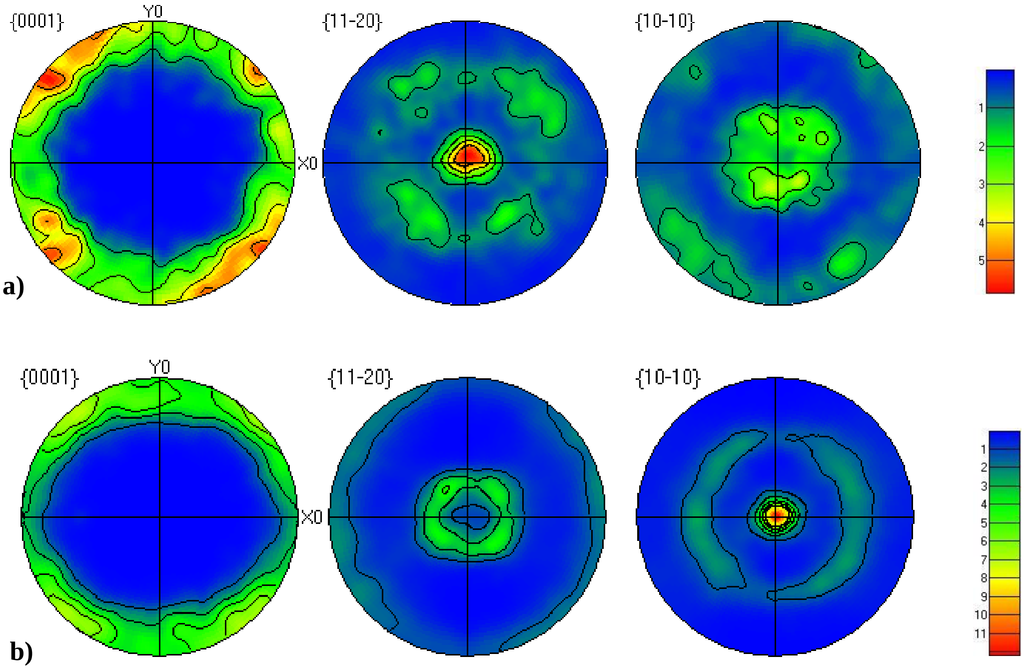

Figure 4. Set of (0001), (11-20) and (10-10) EBSD contoured pole figure from the a) the starting and b) reduced tube. Note, maximum pole figures intensities are given in Table1.