PAPER • OPEN ACCESS

Improving hydro-formability of stainless steel tubes by tube channel pressing

To cite this article: Y Kitano *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **194** 012007

View the article online for updates and enhancements.

Related content

- Influence of Mn contents in 0Cr18Ni10Ti thin wall stainless steel tube on TIG girth weld quality
  Bo Liu
- Increasing the formability of ferritic stainless steel tube by granular medium-based hot forming
  H Chen, D Staupendahl, L Hiegemann et al.
- Optimized Welding of Stainless Steel Tubings for Corrosion Free Exposure to HBr Gas
  Taeko Hattori, Hideki Takagi, Alain Boireau et al.

This content was downloaded from IP address 46.143.212.211 on 23/12/2017 at 09:21

IOP Conf. Series: Materials Science and Engineering **194** (2017) 012007 doi:10.1088/1757-899X/194/1/012007

Improving hydro-formability of stainless steel tubes by tube channel pressing

Y Kitano[1], M Yuasa[2], H Miyamoto[2], M H Farshidi[3], and E Bagherpour[4]
[1]Graduate School of Science and Engineering, Doshisha University, Kyoto, Japan.
[2]Department of Mechanical Engineering, Doshisha University, Kyoto, Japan.
[3]Department of Materials Engineering, Ferdowsi University of Mashhad, Razavi Khorasan, Iran,
[4]Faculty of Metallurgical and Materials Engineering, Semnan University, Semnan, Iran.

E-mail: duq0532@mail4.doshisha.ac.jp

Abstract. Tube channel pressing (TCP), which is one of the severe plastic deformation (SPD) technologies to refine grain size into submicron size for tubular materials, have been applied to ferritic stainless steel tubes for one pass, in order to alleviate ridging and enhance the hydro-formability. It was found that grain-scale shear bands were introduced by one-pass TCP, and texture and microstructure was successfully modified by promoting recrystallization of deformation microstructure, which is otherwise hard-to-recrystallize, in the post-TCP annealing. Elongation to failure, strain-hardening exponent (n-value) and Lankford values of both longitudinal and circumferential directions increased in comparison to with the tube fabricated by conventional process.
Keywords: ridging, formability, recrystallization, randomize, tube channel pressing

1. Introduction
Ferritic stainless steels (FSS) have high corrosion resistance, heat resistance and press workability. Therefore, they have been applied to various industrial applications, mostly as sheets or tubes. For example, tubes of FSS has been applied to exhaust tubes of automobile, which is frequently deformed into complicated shapes by hydro-forming. However, FSS exhibit ridging when they are subjected to tensile plastic strain in the rolling direction leading to reduction of the formability and the early fracture [1]. The ridging is a kind of rumple and it is caused by plastic anisotropy of the so-called colony with similar crystallographic orientations and is a feature of ferritic stainless steel. Therefore, it is important to promote recrystallization and randomize the texture to alleviate ridging.
In our previous study, we demonstrated that the ridging can be alleviated and the formability is enhanced in FSS sheets by equal-channel angular pressing (ECAP) [2], which is one of severe plastic deformation (SPD) methods. It was found that <100>//ND grains effectively recrystallized and changed into other orientations leading to randomization of texture in the post-ECAP annealing. Dense grain-scale shear bands were introduced by ECAP in large grains of <100>//ND which is otherwise hard-to-recrystallize, and promote recrystallization. There are some processes of SPD about tube materials, for examples, tube twisting is effective to impart strains [3]. Recently, modified ECAP was invented for tube materials and called tube channel pressing [4] and TCP which have been successfully applied to aluminium alloys tube to obtain ultra-fine grain (UFG) structure [4]. In the present study, we applied one-pass TCP to FSS tube in order to control texture and alleviate ridging and enhance the formability.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

2. **Experimental Procedure**

2.1. Entire Process
Figure 1 shows entire flow of conventional process and TCP process. FSS (AISI409L) tubes of 42.7 mm in diameter and 1.0 mm in thickness, 25 mm in length were deformed by TCP process for one pass. Before and after TCP process, tubes were annealed. For comparison, the tubes were annealed before TCP as conventional process in order to relieve the plastic strain of as-received state. Tensile test was carried out to evaluate *r*-value, *n*-value and ridging. An optical microscope was used to see microstructure and a laser microscope was used to measure the surface roughness.

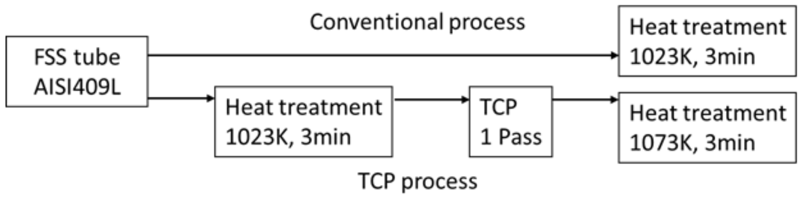

Fig.1 Entire flows of both conventional and TCP process.

2.2. TCP process
TCP is one of SPD process developed by Iranian researchers in order to refine grain size of tube materials [5]. TCP is a modified SPD of ECAP, and intensive shear deformation is given at the bended part of the circular channel. As shown in Figure 2, tube sample is pressed into the die by a tube plunger. In this way, the sample can be pressed for several times until UFG formation. Although, the sample is commonly deformed by simple shear in both ECAP and TCP, there are two important different points. First, there are three to four bended parts where the material is subjected to shear strain in TCP, whereas the typical ECAP has only one, so that billets are subjected to shear strain for several times according to die design in one pass.

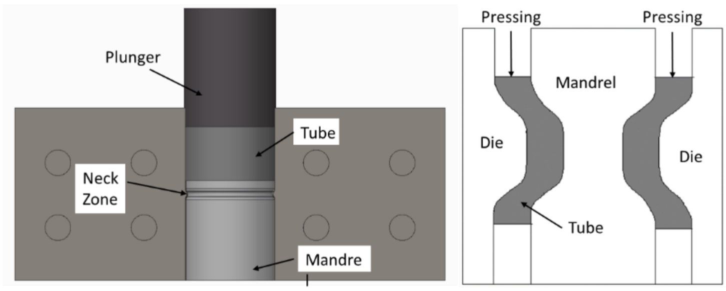

Fig.2 Schematic diagram showing repetitive process of TCP.

3. Results and discussion

3.1. Microstructure
Figure 3 shows optical micrographs before and after TCP. Equiaxial grains before TCP was deformed to elongated shape by shear deformation by one-pass TCP. After TCP, small shear bands are visible inside some grains as shown in Figure 3 (b) and (d). As discussed previous study, such small shear bands are observed in BCC metals such as stainless steels[6], carbon steels[7-10] and IF steels[7,8,11,12], and FCC metals with high stacking fault energy such as aluminum alloys[13-15]. This small shear bands are alternatively called in-grain shear bands [7-9, 11], grain-scale shear bands [13] or micro shear bands [15] by different researchers, and in this paper they are called grain-scale shear bands. It can be confirmed there are shear bands in two directions. This is because there are several shearing points through 1 pass TCP. The tube is squeezed in the radial direction accompanied by thickening of tube

IOP Conf. Series: Materials Science and Engineering **194** (2017) 012007 doi:10.1088/1757-899X/194/1/012007

wall. Thus, shear strain is given in not only through-thickness direction as in ECAP, but also circumferential direction as shown in Figure 3 (e). Vickers hardness and microstructures of neck zone after TCP are shown in Figure 4. They have three shear parts. It is confirmed that Vickers hardness increase as much as every shear part and shear bands increase gradually.

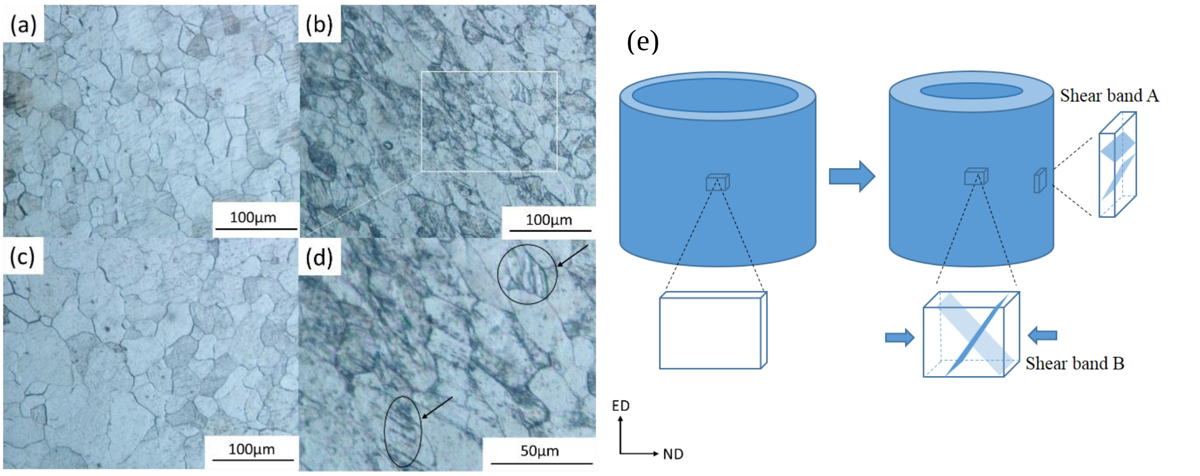

Fig.3 Microstructures of (a) before TCP, (b) after TCP, (c) after final heat treatment and (d) Magnified photo of (b). Arrows in (d) indicate grain scale shear bands and geometry (e) of shear bands A and B formed by shear strain by channel angle and squeezing (reduction of diameter), respectively.

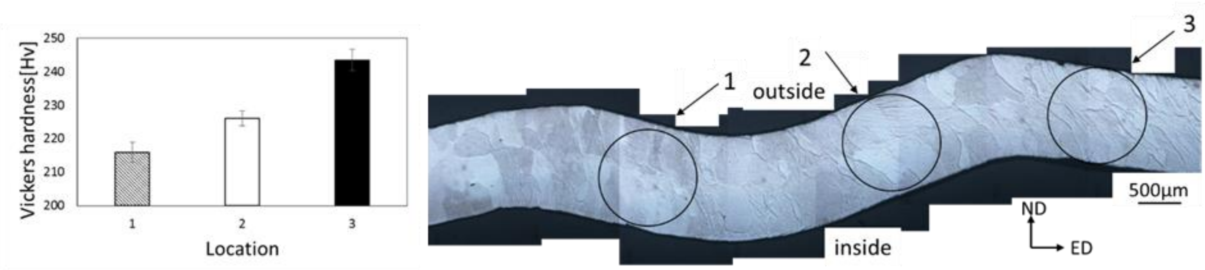

Fig.4 Vickers hardness and microstructures of neck zone after TCP.

3.2. Tensile test

Figure 5 shows the stress-strain curves of axial and circumferential directions. The latter data were obtained by tensile test of ring specimens. Higher elongation to failure in TCP process is evident as shown in stress-strain curve and the photos (Figure 6). Figure 7 shows the relationship between work hardening ratio and true strain of the axial direction, it is evident that the strain hardening rate is higher in TCP process throughout the strain. The strain-hardening exponent (n-value) of conventional and TCP processes are 0.22 and 0.26, respectively. Thus, the tube in TCP process is expected to have higher hydro-formability. Considerable effect is manifest in Lankford value both in axial and circumferential directions as shown in Table 1. Ridging evaluated by tensile test of 15% as shown in Figure 8. Ridging is clearly visible in the conventional process whereas it is mostly alleviated in TCP process. Figure 9 shows {100}-pole figures after the final annealing. Since the tubes are fabricated by electric resistance welding (ERW) of cold-rolled sheets, typical cold-rolled and annealed texture can be recognized in the conventional processing with main components of {111}<112> and {322}<236> orientation. It is known that {111}<112> orientations tends to split into these {322}<236> orientations after cold rolling with very high rolling reduction. In contrast, texture is randomly oriented with no clear peak orientations as shown in TCP process. Thus, TCP and the final annealing randomized texture leading to alleviation of ridging and enhanced formability.

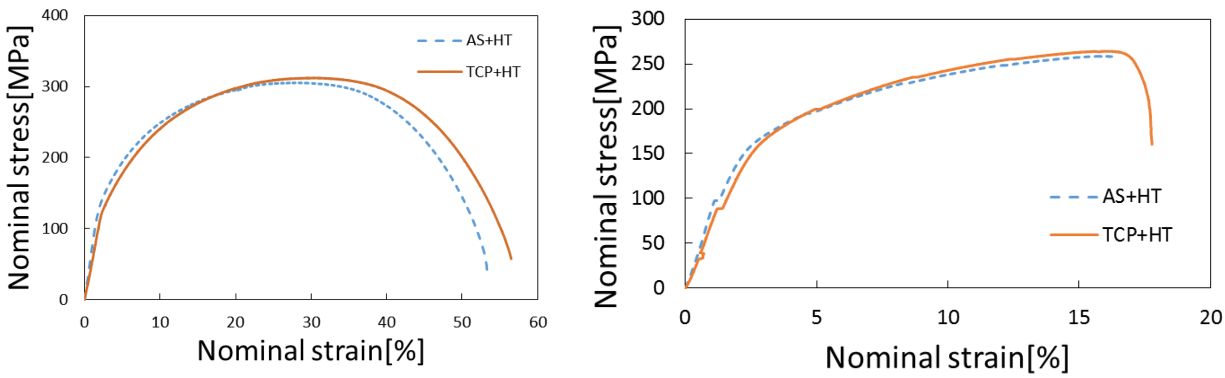

Fig. 5 Stress-strain curves of ring specimens to evaluate tensile behavior of axial (left) and circumferential (right) direction of conventional process and TCP process.

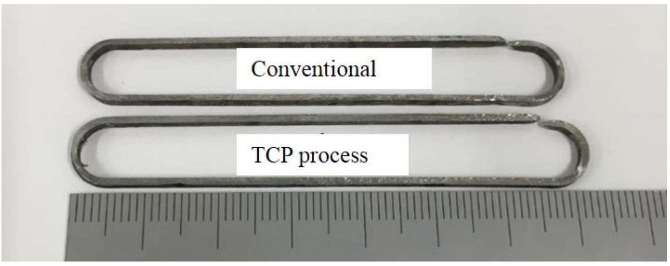

Fig.6 Ring specimen after tensile tests.

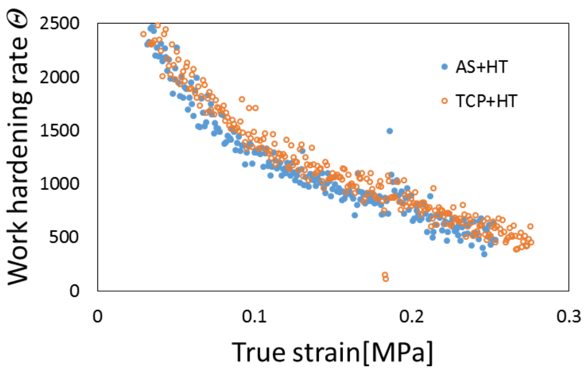

Fig. 7 Relationship between the work hardening rate and true stress of as annealed and 1 Pass of TCP annealed

Table 1 Lankford values of axial and circumferential directions

	axial	circumferential
AS+HT	1.14	0.90
TCP+HT	1.73	1.64

Fig.8 Ridging after 15% tensile elongation of (a) conventional and (b) TCP processing

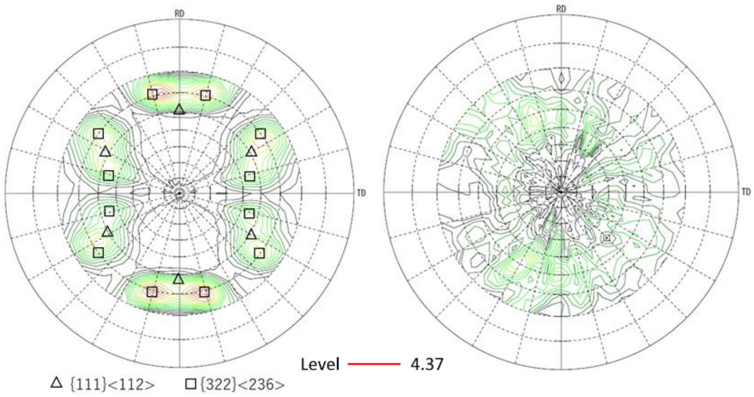

Fig.9 {100} pole-figures after the final heat treatment of conventional and TCP process

4. Conclusions

Tube channel pressing was applied to ferritic stainless steel (Fe-10%Cr) tubes for one pass to examine the effect of TCP on recrystallization microstructure and texture and formability. After one pass TCP, grain-scale shear bands were visible in several grains. These shear bands facilitate recrystallization and randomize the texture. Ridging was alleviated, and both strain-hardening capability and *r*-value was enhanced by one-pass TCP. It can be expected that the hydro-fomability is also enhanced.

Acknowledgement

This work was financially supported by Japan Science and Technology Agency (JST) matching planner program and this support is gratefully appreciated.

References

[1] Chao H-C1973 Recent studies into the mechanism of ridging in ferritic stainless steels *Metallurgical Transactions* **4** 1183-1186
[2] Miyamoto H, Xiao T, Uenoya T, Hatano M 2010 Effect of simple shear deformation prior to cold rolling on texture and ridging of 16% Cr ferritic stainless steel sheets *ISIJ International* **50(11)** 1653-1659
[3] Pougis A, Toth L S, Bouaziz O, Fundenberger J J, Barbier D, Arruffat R 2012 Stress and strain gradients in high-pressure tube twisting *Scripta Materialia* **66(10)** 773-776
[4] Farshidi M H, Kazeminezhad M 2016 The effects of die geometry in tube channel pressing: Severe plastic deformation. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications* **230(1)** 263-272
[5] Farshidi M H, Kazeminezhad M, Miyamoto H 2015 Microstructure and mechanical properties of an Al–Mg–Si tube processed by severe plastic deformation and subsequent annealing. *Materials Science and Engineering*: A **640** 42-50
[6] Zhang C, Liu Z, Wang G 2011 Effects of hot rolled shear bands on formability and surface ridging of an ultra purified 21%Cr ferritic stainless steel *Journal of Materials Processing Technology* **211(6)** 1051-1059
[7] Barnett M R, Jonas J J 1997 Influence of ferrite rolling temperature on microstructure and texture in deformed low C and IF steels *ISIJ International* **37(7)** 697-705
[8] Barnett M R, Jonas J J 1997 Influence of ferrite rolling temperature on grain size and texture in annealed low C and IF steels *ISIJ International* **37(7)** 706-714
[9] Barnett M R 1998 Role of in-grain shear bands in the nucleation of <111>//ND recrystallization textures in warm rolled steel *ISIJ International* **38(1)** 78-85
[10] Nave M D, Barnett M R, Beladi H 2004 The influence of solute carbon in cold-rolled steels on shear band formation and recrystallization texture *ISIJ International* **44(6)** 1072-1078
[11] Jonas J J 2001 Effects of shear band formation on texture development in warm-rolled IF steels *Journal of Materials Processing Technology* **117(3)** 293-299
[12] Chen Q Z, Quadir M Z, Duggan B J 2006 Shear band formation in IF steel during cold rolling at medium reduction levels, *Philosophical Magazine* **86(23)** 3633-3646
[13] Korbel A, Embury J D, Hatherly M, Martin P L, Erbsloh H M 1986 Microstructural aspects of strain localization in Al-Mg alloys *Acta Metallurgica* **34(10)** 1999-2009
[14] Gasperini M, Pinna C, Swiatnicki W 1996 Microstructure evolution and strain localization during shear deformation of an aluminium alloy *Acta Materialia* **44(10)** 4195-4208
[15] Hurley P J, Humphreys F J 2003 The application of EBSD to the study of substructural development in a cold rolled single-phase aluminium alloy, *Acta Materialia* **51** 1087-1102