# CRACKING OF FERRITIC STAINLESS STEEL TUBES DURING PRODUCTION PROCESS

MAJTÁS Dušan[1], KREISLOVÁ Kateřina[2], VIANI Alberto[1], PÉREZ-ESTÉBANEZ Marta[1], GEIPLOVÁ Hana[2]

[1]Centre of Excellence Telč, ITAM AS CR v.v.i., Telc, Czech Republic, EU
[2]SVÚOM s.r.o., Prague, Czech republic, EU

**Abstract**

From the economic reasons many products originally made from austenite stainless steel are nowadays made from ferritic stainless steel. Ferritic steels have relatively low yield strength and the work hardening is limited. They cannot be hardened by heat treatment and only moderately hardened by cold working. Commercially made stainless steel tubes from ferritic steel, used for industrial plumbing was examined on presence of cracks. The cracking was present on the inner side of the convoluted tube shape. The tube manufacturing process consisted of continual bending of the sheet to tube shape, weld the tube, then of cold shaping by pulling through rib-forming frames, which is done in several steps. Then thermal treatment applies to the nearly finished product to remove stress remaining in the structure. Prime suspect was deformation beyond the ductility of used material. However the stress-strain tensile testing does not approved this hypothesis. Several samples of failed material were taken together with reference, and were examined by optical microscopy, and X-Ray Diffraction structure analysis. The structure of the cracked tubes does not show the signs of deformation over the limit, except the location near to the crack itself. Interestingly enough the failed material showed more homogenous structure than the original one. Needle like structures were found when the material is "over-etched", on these structures concentration of stress under bending occur. This structure was identified as δ-ferrite however its presence in α-ferrite matrix is unclear.

**Keywords:** Delta ferrite, metallography, mechanical failure, crystallographic defects

## 1. INTRODUCTION TO THE PROBLEM

The objective of the research was to find cause of defect in stainless steel tubes. These commercially made stainless steel tubes were manufactured from ferritic steel. These tubes are used for industrial plumbing and in civil houses and flats.

The cracks were present on the inner side of the convoluted tube shape. The tube manufacturing process consists of continual bending of the sheet to tube shape and weld the tube using micro plasma. In the next step cold shaping by pulling through rib-forming frames is applied, this procedure is done in several steps. Heat treatment is applied in the end to remove stress remaining in the structure. Examined tubes were without the final heat treatment, directly taken from the production process from the point where the defect occurs.

## 2. HYPOTHESIS AND PREPARATION

The prime hypothesis was the material was deformed beyond its mechanical capabilities, namely, deformed beyond its ductility. However the results of tensile testing we have obtained from manufacturer disapproved this hypothesis.

For the experiments several samples of failed material were taken together with reference. The samples were prepared for optical microscopy using [1] and observed using HIROX 7700 optical microscope. In addition the samples were examined using XRD to determine the structure. To simulate the cracking conditions the manual bending using hand tools was applied to the samples of steel sheets. But this simulation resulted to be insufficient to induce cracking in the material.

## 3. OPTICAL MICROSCOPY

Primarily used Nital etching solution has proven itself to be insufficient to render the grains so the hydrochloric and nitric acid mixture was used (of 1:3 ratio) which proven to be able to render the grains. In addition needle-like structures were also shown on the etched cross sections, not originally present on the cross sections itself (as shown on **Fig. 1**). In addition it was also found, the deformation of the structure has only short range effect on longer distance (600μm and more) the grains were not deformed at all. This is clearly visible in the **Fig. 2**

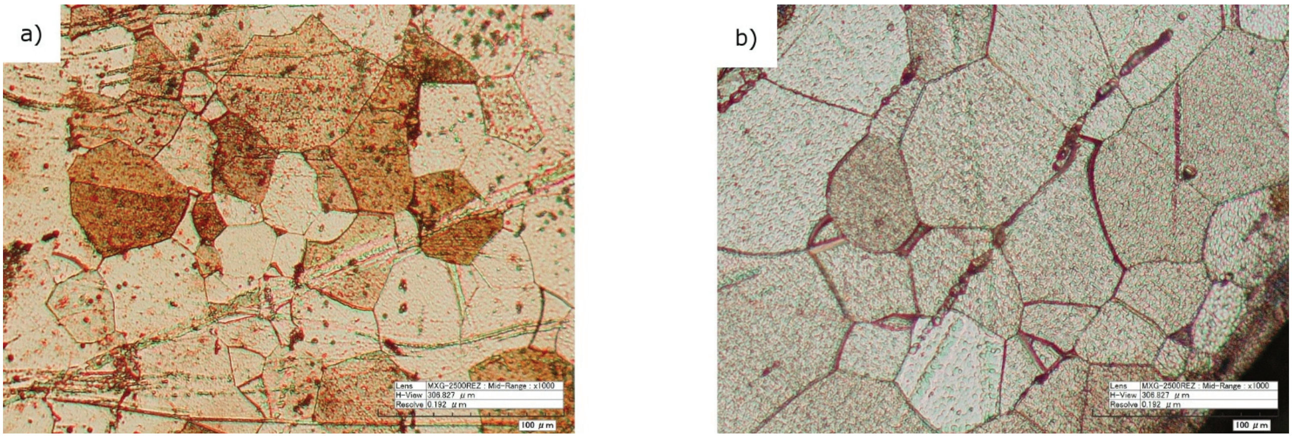


**Fig. 1** Cross section of the material showing needle-like structures and 1b

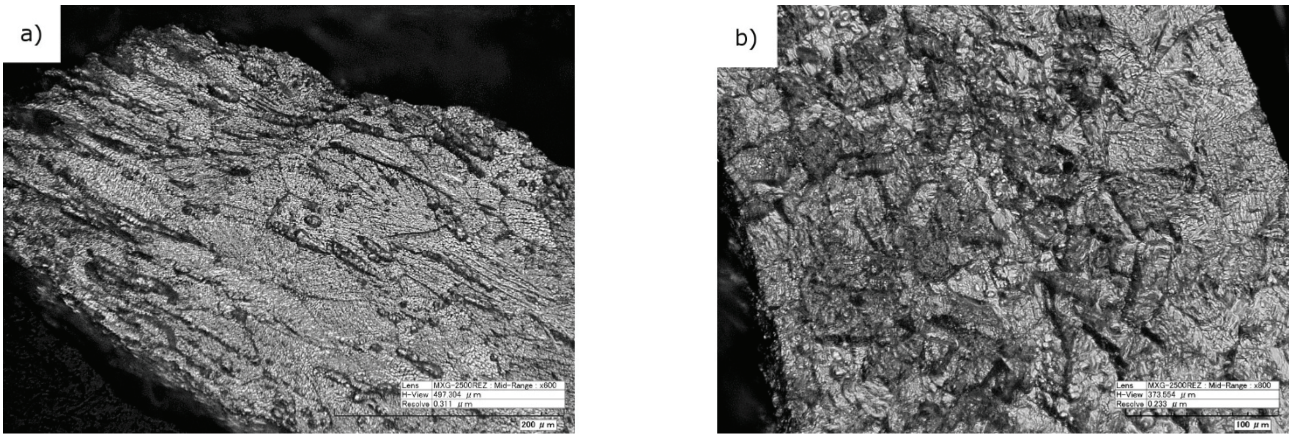


**Fig. 2** Cross section of the failed tube showing elongation of the grains (2a) in near vicinity of the defect but 600 μm away there is no sign of deformation (2b)

According to the literature studied [2-7] the needle-like structures seems to be delta ferritic structures. With one exception, the delta ferrite is present in austenite steels but should not be present in ferritic matrix, where the delta and alpha ferrite should be distinguished from one another, as these are generally same phase. To assure the material examined is ferritic and not austenite as might result from this semi-conclusion. The X-Ray diffraction of these samples was made.

## 4. XRD ANALYSIS

Using the XRD material was identified as AISI 434L which is similar in composition to AISI 444 as it was declared by manufacturer (XRD scan shown on the **Fig. 3**, whereas the compositions are shown in **Tables 1** and **2**). At this point should be noted, the producer of tubes is not a producer of steel sheet. As shown in tables bellow, the composition of those two ferritic steels varies slightly and the misinterpretation of the given material is more likely caused by inhomogeneity in the material in combination with the capabilities of the used method.

In addition to ferritic steel (red lines), presence of silicon carbide (green lines) was found in the samples. This is no doubt caused by the presence of SiC, however this should be handled with caution, as the XRD scan contains some noise and also the SiC was used during the sample preparation (grinding and polishing) among other agents.

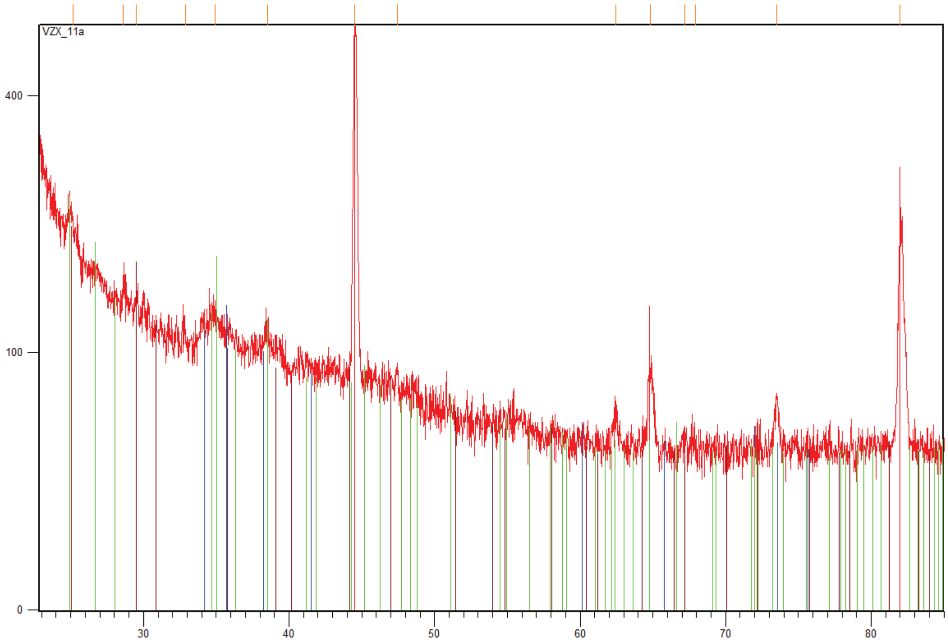


**Fig. 3** XRD scan of the material

We suppose there is some small amount of SiC present in the structure, but its exact amount, and thus the amount of carbide in the structure, should be determined by other method, to overcome the possible false positive identification caused by the noise (and also using different grinding materials if applicable).

**Table 1** Composition of AISI 444 stainless steel (wt.%)

| C | Si | Mn | P | S | Cr | Ni | Mo | Ti | Cu | other |
|---|---|---|---|---|---|---|---|---|---|---|
| <=0.025 | <=1.00 | <=1.00 | <=0.040 | <=0.015 | 17.50-18.50 | - | 1.80-2.00 | 0.12-0.40 | - | Nb=0.25-0.50 |

**Table 2** Composition of AISI 434L stainless steel (wt.%)

| C | Si | Mn | P | S | Cr | Ni | Mo | Ti | Cu | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | 0.90 | 0.20 | 0.01 | 0.02 | 17.00 | - | 1.00 | - | - | |

## 5. DISCUSION

Also additional interesting fact was found during the optical microscopy (as shown on **Fig. 4**). The needle-like structures are oriented parallel to the axis of rolling. On the cross section parallel to the axis the structures seems like scratches, on perpendicular like holes drilled into the material. Also on the parallel cross section the needles seem to copy the shape of the sheet, when the sheet was bent, the needles bend in appropriate direction.

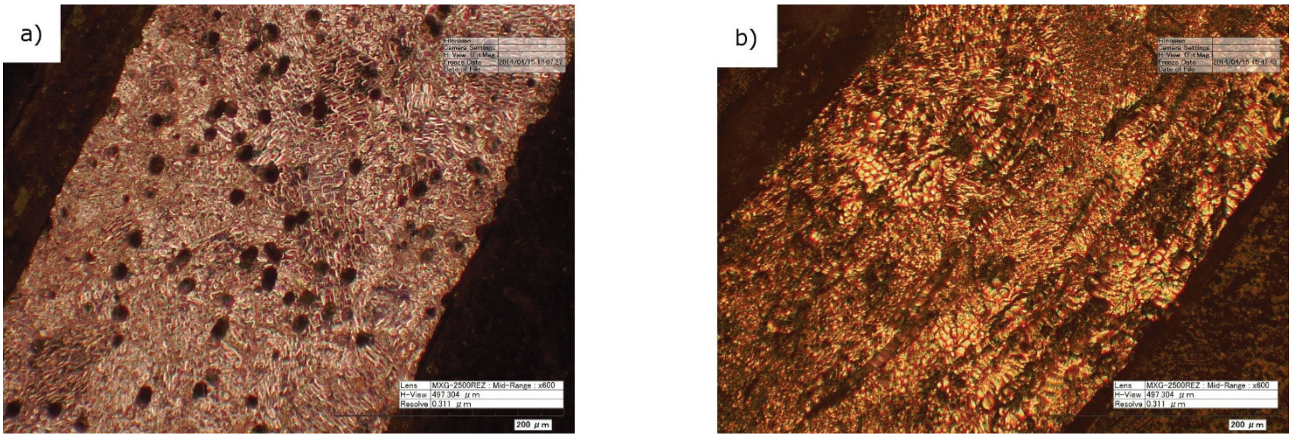


**Fig. 4** Cross section parallel (4a) and perpendicular (4b) to the rolling axis

The simulated bending was not sufficient to induce cracking of those needle-like structures, and thus the crack propagation was not observed on cross sections. But the overall behaviour of the failed material exhibited similar drop in mechanical properties as austenite steels containing delta-ferritic needles, compared to same material without the delta ferrite. However this does not solve the problem how delta ferrite can exist inside alpha ferritic matrix.

It is still possible the failed batch of material is nothing more than production error, however, this statement have to be further tested. If the results are accurate and there is no other phase then ferrite in given steel matrix, the result is rather interesting. Delta ferrite, previously formed inside austenite grains is hidden inside the newly formed grain structure of alpha ferrite. However not limited to stay inside grains but continues through several grains. However this statement should be verified by additional research.

## CONCLUSION

- The drop in mechanical properties, namely when bending and sheer deformation is applied, is in accordance with the concentration of stress alongside the needle-like structures present in the material.
- Needles were not produced during the tube shaping process. Material was thermally treated after the tube was weld to remove remaining stress in the structure and grains do not show any deformation
- The needle-like structures were identified as delta ferrite. The XRD does not show additional iron phase in the given samples and in addition there is no major difference in the internal structure of the grains shown on “over etched” cross sections taken by optical microscope.
- However the origin of the delta ferrite presence remains unclear. There is hypothesis failed material (as it was from one spool of steel sheet and does not present on any other batch) was in fact a production error, but this need further examination.

## ACKNOWLEDGEMENTS

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