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Comparison of Tool Steels for Tube End Flanging

Bence TRAUTMAN,[1] László TÓTH,[2] Enikő Réka FÁBIÁN[3]

[1] *Óbuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Institute of Materials and Manufacturing Sciences, Budapest, Hungary, bencetrautman1@gmail.com*

[2] *Óbuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Institute of Materials and Manufacturing Sciences, Budapest, Hungary, toth.laszlo@bgk.uni-obuda.hu*

[3] *Óbuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Institute of Materials and Manufacturing Sciences, Budapest, Hungary, fabian.reka@bgk.uni-obuda.hu*

Abstract

One of the most important components of a tube end flaring machine is the flanging tool, which is subjected to mechanical stresses such as compression, bending and abrasion. It is therefore very important to choose the optimal material and manufacturing technology for the flanging tool. Böhler tool steel grades K110 and K340 were chosen as the subject of our research. Both materials were used to produce tube flanging tools, which were subjected to hardness testing, microscopic examination and surface wear testing after simple cooling or deep cooling and triple high temperature tempering after austenitisation in a vacuum at elevated temperature. Based on the measurements, the deep cooled and triple tempered K340 steel was found to be the most favourable tool steel for the production of the tube flanging tool.

Keywords*: tool steel, tube* flanging, *heat treatment, wear resistance, microstructure*

1. Introduction

The pipe flange used today has a long history. With the advent of new manufacturing technologies, many previously known manufacturing methods have been superseded (e.g. blind flanges and threaded flanges) and, as in all other areas, the need for standardisation to ensure interchangeability has developed. Flanges are used to connect equipment (pumps, valves, etc.) or additional pipes to the pipelines, and they also facilitate access to the pipes for subsequent installation or repair, if a repair is required within the system. This design is required where equipment and piping operating under high pressure is planned. A profitable tool is needed to make the flanges, as the wide range of uses of the technology means that it must be mass-produced in a cost-effective way, without compromising the tool's lifetime.

Another argument against welding is the knowledge that the welded joint environment can easily and often quickly corrode **[1–3]**, and that the grain size in the heat-affected zone can become coarse during welding, leading to a deterioration of the mechanical properties of the material **[4]**. The desire to prevent this, particularly in the interests of safety and sustainability, has become a fundamental principle.

In view of this, and in response to a constant assessment of market needs, the T-Drill company, which has been known since the 1960s for its pipe-machining machines and their manufacture, developed the cold-forming deep-drawing method. Modern cold-forming flanging technology is a technical process that reduces production time and costs by more than 40% compared to traditional welding.

This technology reduces the need for welding to a minimum and at the same time represents a qualitative leap, especially for systems used in the food industry, as the medium transported in the pipeline no longer encounters the weld root containing contaminants and the quality achieved meets hygiene requirements.

In the light of this achievement, the question arose: how could the flange of the pipes be designed in a different way? In answering this question, T-Drill has created a major technological innovation, but its primary task was to flange light metals. The innovation was suitable as long as small diameters and low pressures had to be dealt with, but at the same time it became necessary to carry out further research and development into ways of flanging steel tubes that could cope with larger diameters and pressures.

This has led to the development of the technology that is now known and used worldwide: cold-formed pipe flanging. An essential tool and instrument for this is the tube flanging machine, of which the Tube flanging tool is an important part (**Figure 1**).

When using a flanging tool, it is subjected to compressive, abrasive and bending stresses, which reduce the tool life and thus increase the frequency of tool changes. This not only means the need for more flanging tools, but also poses a challenge for tool manufacturers. With these features in mind, Böhler K110 and K340 tool steels were chosen.

Both steel grades are ideal in terms of performance and price/value ratio, but heat treatments significantly affect the grain structure **[5, 6]** and thus the wear behaviour **[7, 8]**. of the steels. Gavriljuk et al **[9]** investigated the effect of cryogenic treatment on the martensitic transformation, Das et al **[10]** studied the carbide precipitation in similar cold forming tool steels. Other researchers **[11, 12]** dealt with changes in mechanical properties, and others **[13, 14]** with the effect of cryogenic treatment on wear properties. For our investigations, we first applied high temperature hardening and triple high temperature tempering on K110 and K340 materials, and then we also investigated K340 material grade specimens after high temperature hardening, deep cooling and triple high temperature tempering. Our tests were Rockwell hardness, abrasion, Charpy impact test and light microscopy studies for microstructure.

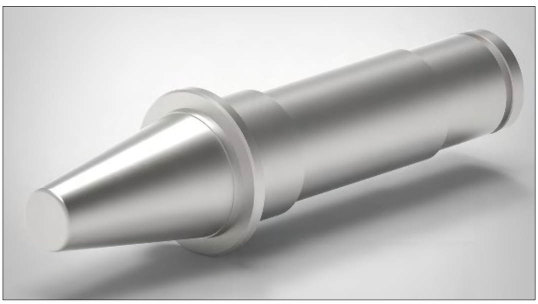

Figure 1. *Tube flanging tool.*

2. Materials, tools and technologies

K110 is a high carbon and chromium cold forming tool steel with good toughness and, due to the presence of carbide formers, excellent wear resistance. It is a recommended raw material for cold forming tools. Böhler grade K110 has EN number 1.2379, EN symbol X153CrMoV12, AISI symbol D2.

K340 Isodur is a universal cold forming tool steel grade with good compressive strength, wear resistance, excellent toughness and low dimensional change during heat treatment. It is produced by electroslag remelting and therefore has high purity and a favourable solidification structure. This steel has a low level of non-metallic inclusions due to its production technology. We have chosen these grades because their achievable properties meet the requirements of our tool material **[4]** The composition of our test specimens from K110 and K340 materials is presented in **Table 1.**

The hardness of the materials measured in their transport state ranged from 210 to 220 HB, so they are highly machinable. Our bar materials were turned into flanging tools - being a rotationally symmetrical product-. For heat treatment, we used a vacuum furnace type IU72/1F 2RV 60x60x40 10 bar CP Schmetz with an operating temperature range from -150°C to 1300°C, which was used for hardening, deep cooling and tempering (**Figure 2**).

Two different heat treatment technologies were used for grade K340. In the first case, high temperature (1060°C) quenching was followed by triple high temperature tempering (545, 555,

Table 1. *Chemical composition of K110 and K340 steels*

	C	Si	Mn	Cr	Mo	V
K110	1.55	0.30	0.30	11.30	0.75	0.75
K340	1.10	0.90	0.40	8.30	2.1	0.5

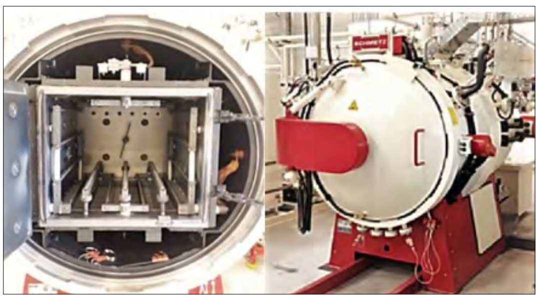

Figure 2. *Vacuum heat treatment furnace.*

535 °C), in the second case, after high temperature austenitisation, (1060°C), deep cooling with liquid nitrogen (–150°C) was followed by triple high temperature tempering (545, 555, 535 °C). Deep-cooling was chosen because it is a method to reduce the amount of residual austenite, to almost zero. The residual austenite would have a detrimental effect on the material by causing inhomogeneity and stresses. The heat treatment of the sample made by deep cooling was carried out as follows (**Figure 3)**.

The heat treatment process for K110 tool steel is illustrated in **Figure 4**.

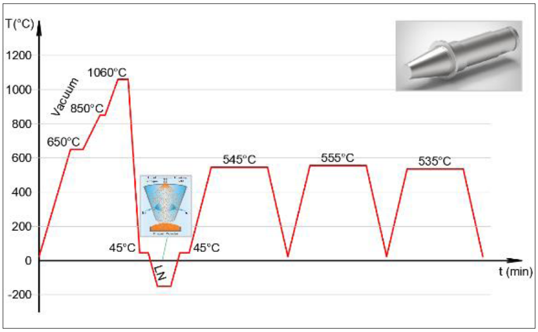

Figure 3. *Cryogenic heat treatment diagram for K340 steel.*

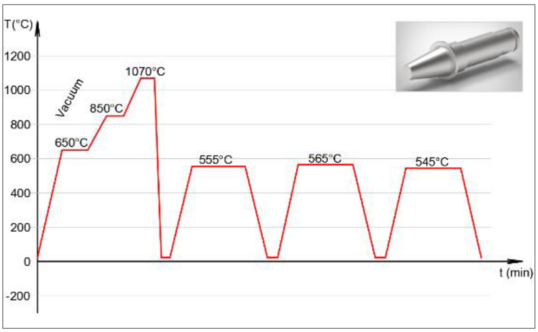

Figure 4. *Heat treatment diagram for K110 steel.*

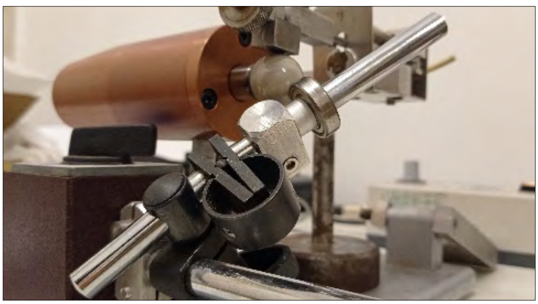

Figure 5. *Abrasive equipment.*

3. Measurements and tests

After the heat treatments, hardness measurements were taken using an Ernst AT-130 hardness measuring machine, Then the tools were ground to the correct size. The specimens for the tests were machined into samples for the abrasion test. A picture of the abrasion apparatus is shown in **Figure 5.**

Ceramic balls with 20 mm diameter aluminium oxide based polished surface were used for the test. The duration of the measurements was 10 minutes and the speed was 570 rot/min in all cases..

The diameters of the abraded impressions were measured using an Olympus DSX1000 microscope. The image below shows a light microscope image of an abraded specimen (**Figure 6**).

The wear coefficient (*K*) was taken as a measure of wear, and can be calculated from the load force (*N*), wear volume (V_v) and wear path length (*S*). The calculations are based on the following formulae.

$$K = \frac{V_v}{S \cdot N}, \tag{1}$$

Where the wear volume can be derived from the depth of the spherical glass (*h*) and the diameter of the wear mark.

$$V_v = \frac{h \cdot \pi}{6}\left(\frac{3}{4}d^2 + h^2\right), (mm^3) \tag{2}$$

The resulting spherical glass depth is calculated from the abrasive ball radius (*R*) and the diameter of the abrasion impression ($d = 2R$).

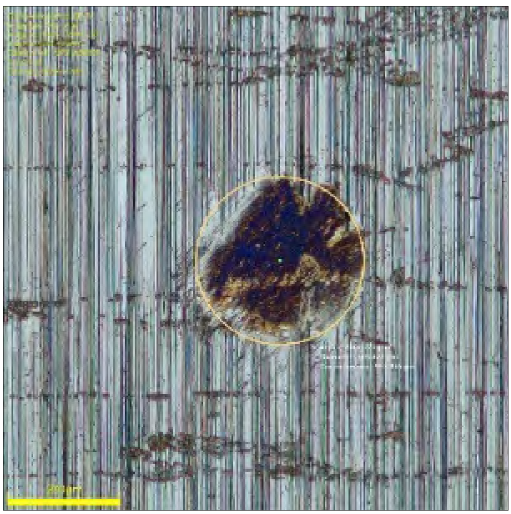

Figure 6. *Abraded print*

$$h = R - \sqrt{R^2 - \left(\frac{d}{2}\right)^2}, \qquad (mm) \tag{3}$$

In addition, the wear path length can be determined by the radius of the abrasive sphere and its rotational speed (n):

$$S=2\cdot\pi\cdot n\cdot R\cdot t,(m) \tag{4}$$

In preparation for further microstructure studies, the samples were embedded in resin, polished, polished and etched with 2% Nital and examined under a Neophot 2 microscope.

The hardness measurement results and the obtained wear factors are summarised in Table 2.

The wear factors of samples with different heat treatments are illustrated in Figure 7.

The measured values show that the most abrasion resistant sample was the deep cooled and tiple tempered K340 grade steel, as confirmed by the microstructure.

The wear is presumably related to the microstructure. To investigate the microstructure, the samples were embedded in resin, sanded, polished and etched with 2% Nital and examined under a Neophot 2 microscope.

Since Nital does not etch carbides and austenite, the appearance of carbides in the samples, their distribution and the characteristics of the matrix surrounding the carbides could be examined at different magnifications.

Examining the samples at relatively low magnification, K110 steel shows a carbide network structure (Figure 8), whereas K340 grade is so typical because this steel was produced by electroslag remelting.

In each of these materials, typically slightly larger fragmented carbides are seen in the original grain boundaries (Figure 8), while in the matrix the carbides are much finer and more coarse-grained. For all steels the grain size is around 20 μm.

In the matrix of the K110 steel, fine spherical carbides are visible in addition to the stick-like carbides, while in the matrix of K340 steel the appearance of carbides are typically spherical (Figure 9).

In the light microscopy studies, it was found that when the K340 steel sample was austenitized at 1060°C, cooled under conventional conditions and then strained three times, residual austenite was still present in the fine structure matrix, whereas when the systematisation was followed by deep cooling and then the three times strain hardening at 1000x magnification, no residual austenite was

Table 2. *Measurement results*

Sample	Hardness HRC	Wear index (K) (mm^3/Nm)
K110	60	05.00E-08
K340	59	04.49E-08
K340 deep cooled	60	04.40E-08

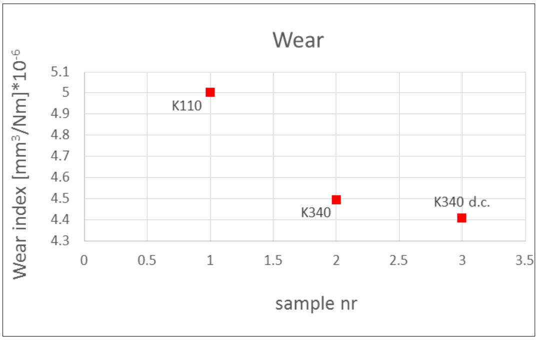

Figure 7. *Wear factors of the tested samples.*

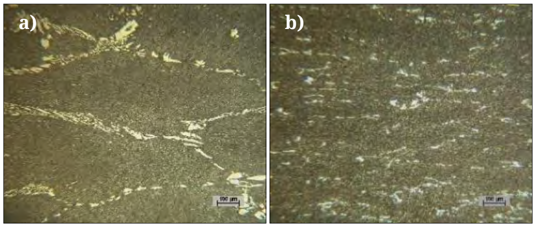

Figure 8. *The appearance of carbide. Nital2%, N=100x, a) K110, b) K340.*

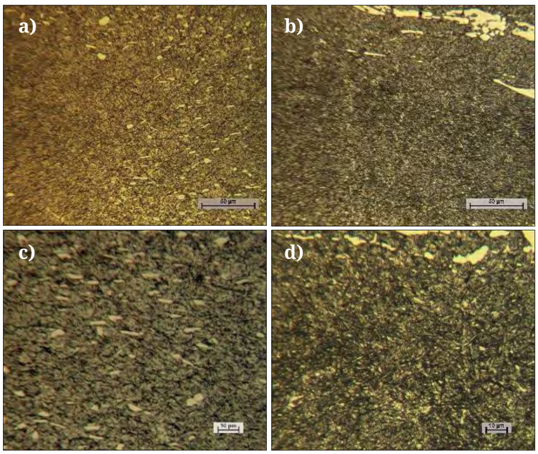

Figure 9. *The matrix characteristics after usual heat treatments of the studied steels Nital 2%, a) K110 N=500x b) K340 N=500x c) K110, N=1000x d) K340 N=1000x*

detected (**Figure 10**). In the photos carbide are spheric, the austenite appear between tempered martensite- (no spheric).

4. Conclusion

K110 is a good material grade, with good wear properties and hardness value, however microscopic tissue structure analysis demonstrates that it has a carbide reticulated structure, whereas this is not the case for the remelted material. In the K340 steel, the electroslag remelting results in a more homogeneous, finer and more uniform carbide distribution in the microstructure. In the microstructure of the K340 deep-cooled sample, residual austenite is typically not found, so no dimensional change after heat treatment is assumed in our sample and its lifetime is expected to exceed that of the previous two samples. The best resistance to wear of the deep-hardened and triple-strengthened K340 steel is due to the homogeneous carbide distribution and the fully transformed grain structure. Thus, the high temperature hardened, deep hardened and triple high temperature tempered K340 tool steel seems to be the most suitable material for the pipe milling tool of our choice. It is hoped that practical experience will bear this out.

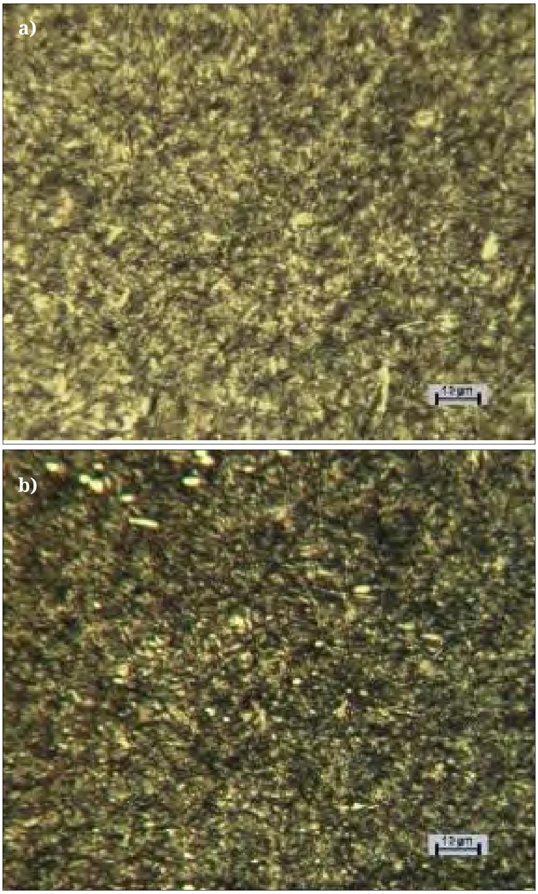

Figure 10. *Residual austenite in the steels K340 a) conventional heat-treated sample , b) deep cooled.*

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