1992

Improved Characteristics of Stainless Compressor Valve Steel

S. Olsson
AB Sandvik Steel; Sweden

Olsson, S., "Improved Characteristics of Stainless Compressor Valve Steel" (1992). *International Compressor Engineering Conference.* Paper 884.
https://docs.lib.purdue.edu/icec/884

IMPROVED CHARACTERISTICS OF
STAINLESS COMPRESSOR VALVE STEEL

Sören Olsson
Research and Development Centre
AB Sandvik Steel
S-811 81 Sandviken, Sweden

ABSTRACT

The conclusions of an experimental program involving altered tensile strength and microstructure of stainless compressor valve steel are described. The paper presents the results of measurements of ductility, corrosion resistance, bending fatigue strength and damping. Encouraging indications have been achieved concerning the possibilities to further improve the characteristics of current material.

1 INTRODUCTION

One of the essential properties of a compressor valve steel is its ability to resist the stresses, created by the repeated bending of the valve without fracturing. The material parameters which control this fatigue strength are in principle well known. For example, a high static strength and compressive surface stresses contribute to improved fatigue strength, while rough surfaces and corrosion have the opposite influence.

Since long, there have been two types of materials available for the manufacture of compressor valves, one being carbon steel with a composition corresponding to AISI 1095. The other is a martensitic chromium steel based on AISI 420 but with an addition of 1 % Molybdenum.

The fatigue strength of compressor valves manufactured from these steel types has probably increased by the development of

- metallurgical processes giving cleaner steels and
- valve manufacturing methods resulting in improved edge and surface properties and controlled surface stresses.

On the other hand, only marginal changes have been made concerning mechanical properties of compressor valve steels since specifications were originally set. Corrosion has been a limited problem in most compressor applications why little attention has been paid to corrosion resistance of the stainless grade.

As service conditions in the compressors currently are subject to change, partly as a result of new refrigerants and lubricants being introduced, a gradual substitution of carbon steel valves seems to take place, favouring the stainless material. In addition, compressor designers have the ambition to increase the efficiency of compressors which makes for higher mechanical load on the valves.

For the reasons indicated above it has been considered to be of interest to evaluate the potential for improved characteristics of stainless compressor valve steel. In this paper, the results of an experimental program will be discussed.

2 EXPERIMENTAL

The tested material was Sandvik 7C27Mo2. Nominal composition and specified tensile strength of this material is given in table 1.

Trial strips with thicknesses ranging between 0.152 mm (.006") and 0.508 mm (.020") were hardened and tempered to tensile strength levels above the upper limit of the currently valid specification range. The heat treatment was made in the normal production equipment. These experimental strips were characterized concerning their mechanical properties. As elevated tensile strength normally causes reduction of the ductility of a steel, extra emphasis was put on ductility measures. Some of the strips were exposed to fatigue testing. The resistance to pitting corrosion was evaluated and an attempt was made to measure the damping properties of the material. Microstructures were assessed.

In connection to each of the following paragraphs a more detailed description of the testing techniques will be made.

3 RESULTS

For reference purposes, a random selection of data for Sandvik 7C27Mo2, manufactured to the standard specification, was made. This set of data has been collected during the past time by regular investigations of compressor valve material.

3.1 Tensile properties

Tensile test bars were cut parallel to the direction of rolling. Size and preparation of the test bars and parameters for testing were in accordance with Swedish Standard SS-EN 10002-1, ref. 1. Testing was made in either a Roell-Korthaus or an Instron tensile tester.

The measured tensile strengths will in the following be used as independent parameter when the various properties are described. It may however be mentioned that the strips included in the investigation had tensile strength values in the range 1780 MPa (258 ksi) to 2010 MPa (291 ksi),see table 2.

3.1 Microstructure

Assessments were made by light optical microscope, LOM, on transverse cross sections to quantify the needleness of the martensitic matrix and the content of undissolved carbides. In addition, the content of retained austenite was measured in a magnetic balance, a device in which the displacement of the sample, when exposed to a strong magnetic field, can be registred. From this, the contents of magnetic and nonmagnetic phases in the material can be calculated.

The microscopic investigations of material revealed only small variations between samples hardened to different tensile strength levels. Martensite needleness could be characterized as fine to undistinguishable and the carbide content was high. This is normal for the material.

The same way as with tensile strength, the measured content of retained austenite will in the following be used as independent parameter when different properties are described. Table 2 gives minimum and maximum contents for the investigated material.

3.3 Ductility

The ductility has been evaluated with two techniques.

At tensile testing the elongation, A-11.3, was measured. A-11.3 is defined as the percentage of elongation on a gauge length which is 11.3 A_o where A_o is the initial cross sectional area of the test bar. Figure 1a shows how the elongation varies with the tensile strength and figure 1b illustrates the relation between elongation and content of retained austenite. In both cases the least square fits indicate that the ductility improves when tensile strength and retained austenite content respectively are increasing.

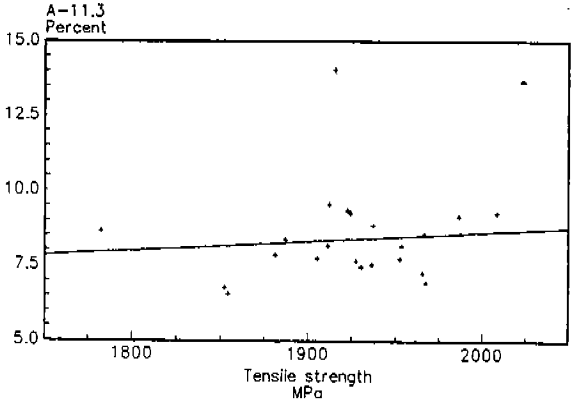

Figure 1a.
Elongation A-11.3 as a function of the tensile strength.

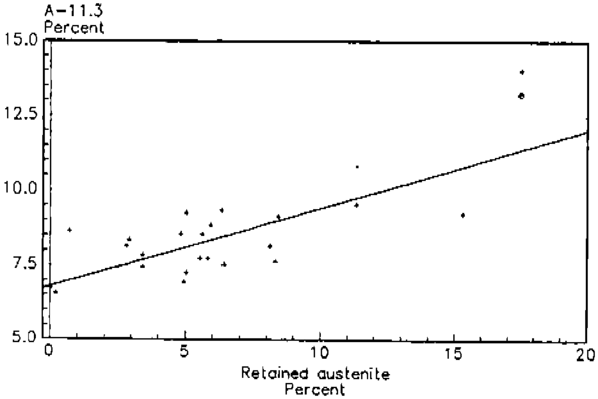

Figure 1b.
Elongation A-11.3 as a function of the percentage of retained austenite.

The other evaluation of the ductility was made as a bendability test. 7 mm wide specimens were cut from the strips, both along and across the rolling direction. The specimens were then bent between the jaws in a vice, one of the jaws being fixed and the other being driven at constant speed by a pneumatic cylinder. The measure of ductility is the distance between the jaws at the moment of cracking, detected by accoustic emission, divided by the specimen thickness.

In figure 2 the bendability values as function of tensile strength (2a) and retained austenite (2b) are presented. These diagrams are valid for bending axis perpendicular to the rolling direction. The corresponding diagrams for bending axis parallel to the rolling direction are shown in figures 3a and 3b. In all diagrams each data point represents the average of 5 specimens.

The diagrams indicate that the ductility, measured with the bendability technique, is improving when both tensile strength and retained austenite content are increasing. It thus seems evident that the results of elongation and bendability measurements are consistent with each other.

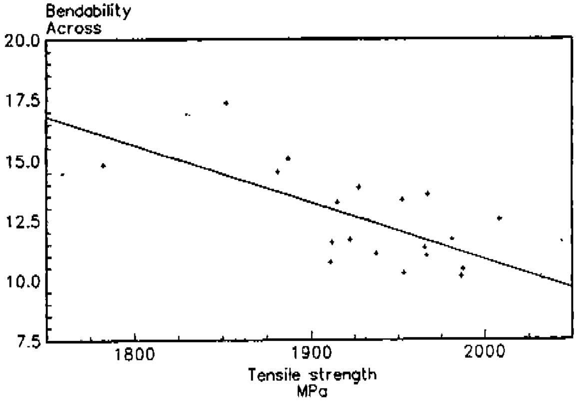

Figure 2a.
Bendability value for bending axis perpendicular to the rolling direction as a function of the tensile strength.

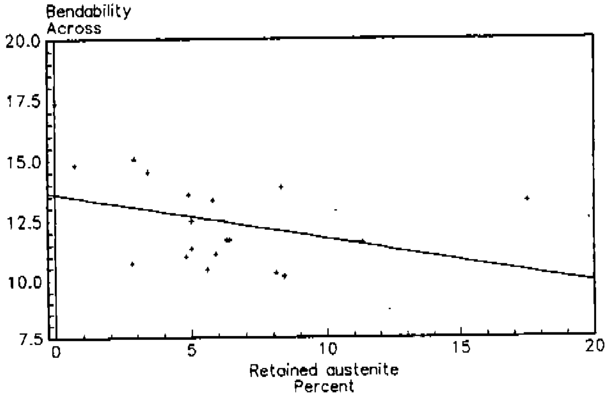

Figure 2b.
Bendability value for bending axis perpendicualr to the rolling direction as a function of the retained austenite content.

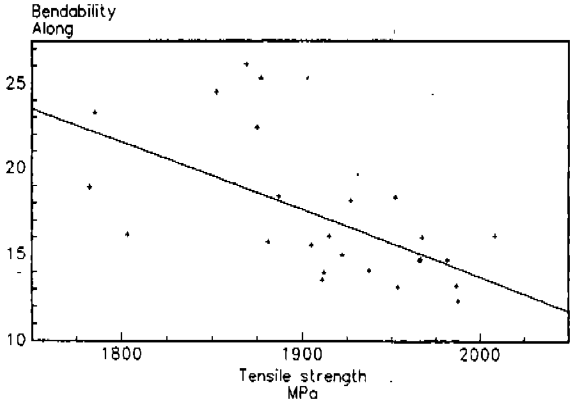

Figure 3a.
Bendability value for bending axis parallel to the rolling direction as a function of the tensile strength.

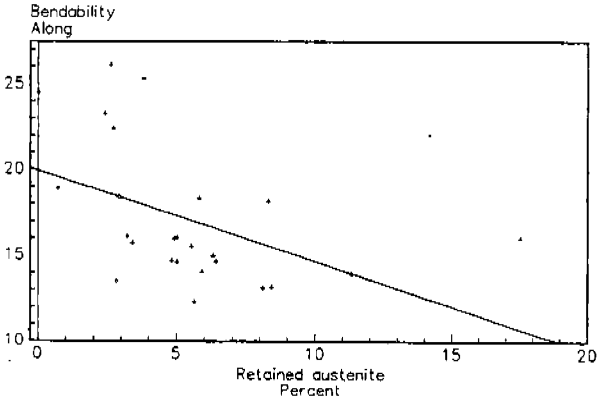

Figure 3b.
Bendability value for bending axis parallel to the rolling direction as a function of the retained austenite content.

3.4 Corrosion resistance

Corrosion resistance can be measured in many different ways but it is difficult to find a laboratory test that can account for the different conditions which may occur in the application. We have chosen to assess the resistance to pitting corrosion, as corrosion pits, if they are formed at compressor valve surfaces or edges, are likely initiation sites for fatigue failures. To quantify the resistance to pitting a technique named CPT, Critical Pitting Temperature, was used. A small specimen, blanked out of the strip and with deburred edges, is immersed in a corrosive solution and is held at a predetermined potential in relation to a reference electrode. The temperature of the solution is gradually increased from ambient level to the temperature where a break through of the passive surface oxide occurs. The break through is detected by a current density peak and the temperature at which this occurs is the CPT. The method allows for comparisons between different materials but does not, as said above, simulate the actual service conditions in a compressor concerning the corrosive agents, their concentration or the temperature.

In our evaluation a 0.1 % sodium chloride solution and a potential of +150 mV were chosen.

In figure 4 the CPT has been plotted as a function of the retained austenite content.

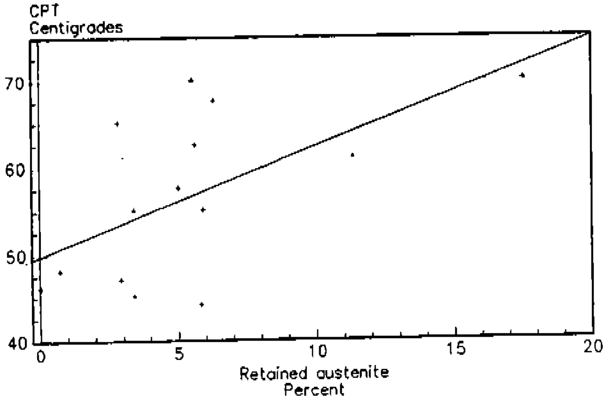

Figure 4.
Critical pitting temperature, CPT, as a function of the content of retained austenite.

The general trend is that the pitting corrosion resistance is improving when retained austenite increases. The improvement is however not caused by the retained austenite as such. The mechanism will be further discussed in paragraph 4.

3.5 Bending fatigue strength

Bending fatigue strength was evaluated in so called UMG machines using specimens with trapezoidal waist which were blanked from the strips with the longitudinal axis parallel to the rolling direction. The specimen edges were prepared with considerable care to avoid fatigue initiation from remaining imperfections. Thus, first machine grinding, then manual polishing was applied. The specimen surfaces were kept untreated. The testing was made according to the stair case method to find the fatigue limit for 50 % probability of failure at $2x10^6$ cycles. To achieve acceptable statistical reliability of the fatigue limit, 30 specimens of each material were run. Futher details about the experimental procedure and specimen geometry may be found in a previous report, ref. 2.

Figure 5a shows that the effect of the tensile strength on the fatigue limit within the investigated range is very small. The general "rule of thumb", that fatigue strength is proportional to the tensile strength, has not been verified by our investigation. On the other hand there seems to be a positive influence on the fatigue limit from elevated contents of retained austenite, see figure 5b.

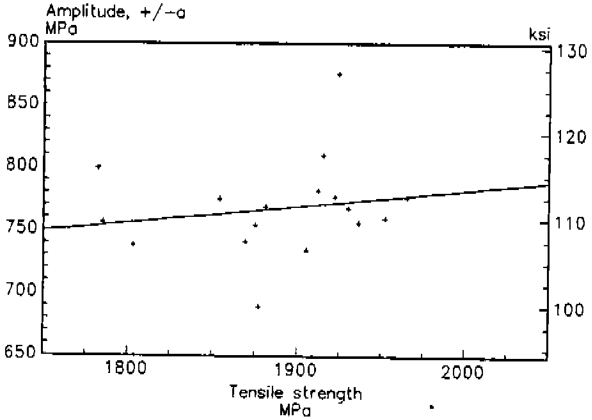

Figure 5a.
Bending fatigue limit plotted against the tensile strength.

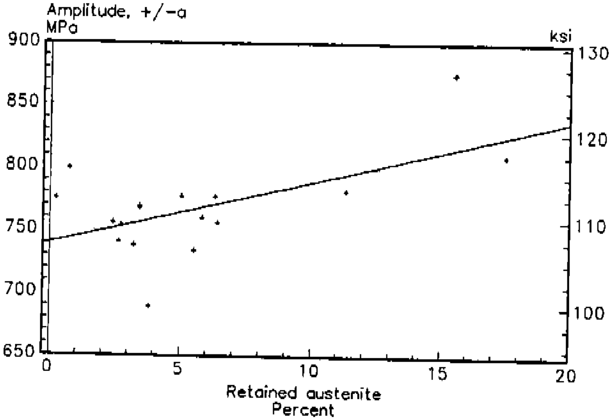

Figure 5b.
Bending fatigue limit plotted against the content of retained austenite.

3.6 Damping properties

Damping can simplified be described as the ability of a material to absorb energy by some internal friction mechanism. A material with good damping characteristics can be expected to absorb induced stress peaks more efficiently than a material with bad damping properties. In compressor applications the damping ability of the valve material can be expected to be of importance when it comes to minimizing damages from the impact between valve and seat/stopper.

In the past only limited attempts have been made to assess damping properties of compressor valve steels. However, in this investigation we judged it to be valuable to try to find out if there is any influence on the damping characteristics from for example the microstructural appearance of the material. To measure the damping a set up according to figure 6a was used.

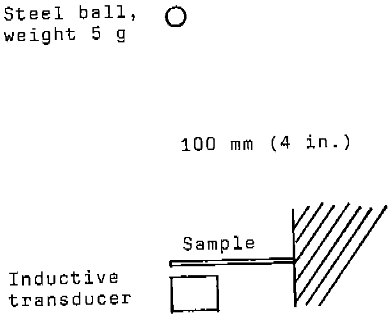

Figure 6a.
Schematic set up for damping measurements.

A steel ball weighing 5 g was allowed to fall from a height of 100 mm (4 in.) to hit the tip of a 20 mm (.079 in.) wide specimen of the material being fixed at the other end. The free length of the specimen was chosen to correspond to that resulting in a vibration with the resonance frequency. (This length is known by experience from our work with impact fatigue testing, which requires the resonance frequency to produce stable movement of the specimen. By example, the suitable length for thickness 0.381 mm (.015 in.) is 50 mm (2 in.)).

As a result of the hit by the steel ball a vibration will be induced in the specimen and will then gradually decay.

To register the vibration progress an inductive transducer, placed 5 mm (.20 in.) below the specimen tip was used. The signal from the transducer was picked up by an oscilloscope, Gould Digital Storage Oscilloscope 4040, resulting in pictures like the one in figure 6b which has been photographed from the oscilloscope screen.

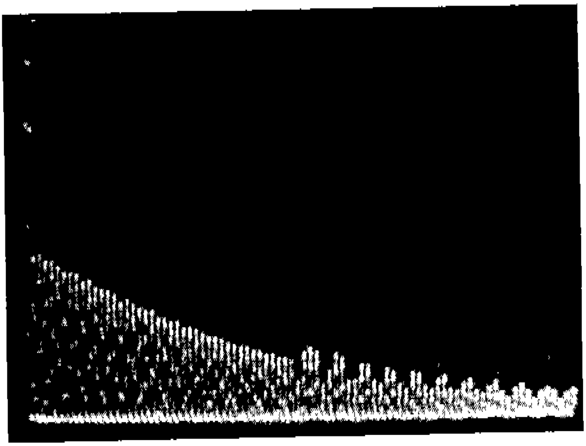

Figure 6b.
Progress of vibration as registered by the oscilloscope.

This progress could then be plotted for evaluation. As the decay of the vibration seems to follow an exponential curve it was decided to make the evaluation by calculating the logarithmic decrement, δ, by making use of the formula:

$$\delta = \frac{1}{N_{ij}} \ln \frac{A_i}{A_j} \qquad \text{(ref. 3)}$$

A_i is the amplitude of peak i and A_j is the amplitude of peak j,

N_{ij} is the number of cycles between peaks i and j.

The evaluation was made for the first to the fifth peak and for the first to tenth peak respectively. The latter corresponds to a vibration time of approximately 75 ms. The reason why only the initial stage of the curve was evaluated is that stress peaks applying to compressor valves have short duration when impacts between valve and seat/stopper is considered.

Figure 6c illustrates the logarithmic decrement for 1st to 5th and 1st to 10th peaks respectively when plotted with the percentage of retained austenite on the x-axis. It seems as if there is no effect at all on the damping characteristics from retained austeniteor possibly that there is a weak positive effect in the earliest stage of the progess.

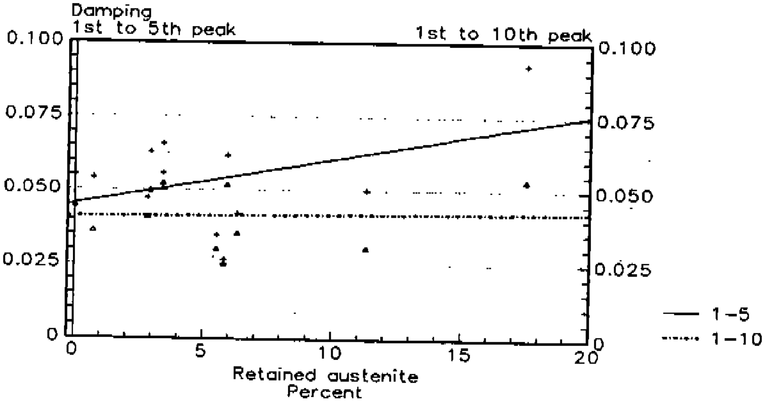

Figure 6c.
Damping from 1st to 5th and from 1st to 10th peaks versus retained austenite content.

DISCUSSION

The results in the present investigation of increased tensile strength level in stainless compressor valve steel are encouraging, yet not indisputable in all respects. Ductility measures, represented by elongation to fracture (figures 1) and by bendability (figures 2 and 3) show, that contrary to what is considered as a normal behaviour the ductility improves at elevated tensile strength. This effect can most probably be attributed to the higher percentage of retained austenite associated with the increased tensile strength. As retained austenite is a soft microstructural constituent and is finely distributed in the martensitic matrix it has the ability to absorb plastic deformations and thereby improve ductility.

Corrosion resistance may be of larger importance in the future due to the possible corrosivity of new refrigerants and compatible lubricants. It is therefore satisfactory to find that there is a potential for improved resistance to pitting corrosion of stainless compressor valve steel (figure 4). This is of course not unexpected as the improvement can be attributed to higher contents of chromium and molybdenum dissolved in the matrix of the steel. This in its turn is a result of a higher degree of carbide dissolution during the austenitizing which has taken place at higher temperature to achieve increased tensile strength.

The results of fatigue testing show a considerable scatter why the conclusion that elevated tensile strength and content of retained austenite improve the fatigue strength is not obvious or certain. It must however be emphasized that fatigue strength is one of the more complex technological properties of a metallic material and is influenced by a number of other parameters than those being considered in the present investigation. For example the materials involved in the investigation origin from several heats and production lots, the test specimens have been prepared and run at different occasions. This indicates that it is not only tensile strength and retained austenite that have varied but also several other parameters. Despite this, positive tendencies can be observed (figures 5).

Damping, the way as it has been assessed, seems to be insignificantly affected by the content of retained austenite except possibly for the very earliest stage. As damping is expected to have an influence on the impact fatigue strength it is of interest to evaluate this property and we have the ambition to do so in a future continuation of this project.

We consider it encouraging to have observed regression lines with "correct direction of the slope" for all investigated properties. The technique used to elevate the tensile strength, high austenitizing temperature, is generally considered to have an adverse effect on material properties due to the grain growth that occurs. However, this phenomenon has in our case been avoided by development of a steel with improved response to heat treatment whereby grain size has been maintained at "fine" level.

CONCLUSIONS

The present investigation has given indications that there is possibility to improve ductility, resistance to pitting corrosion and bending fatigue strength of stainless compressor valve steel by increasing the tensile strength and by giving the material a microstructure consisting of tempered martensite with a fine distribution of retained austenite.

ACKNOWLEDGEMENTS

Thanks to intensive work by several collaborators at the R&D Centre it was possible to finish this paper. The permission by AB Sandvik Steel to publish the paper is also acknowledged.

REFERENCES

1. Swedish Standard SS-EN 10002-1
2. Johansson, R. and Persson, G. Influence of testing and material factors on the fatigue strength of valve steel. 1976 Purdue Compressor Technology Conference.
3. Simpson, H.M. and Pearson, V. Simple apparatus for measuring the dynamic shear modulus of cylindrical specimens. Rev. Sci. Instrum. 50 (4), April 1979.

Table 1

Chemical composition (nom.), %					Tensile strength	
C	Si	Mn	Cr	Mo	MPa	Ksi
0.38	0.40	0.55	13.5	1.0	1800±80	261±11.5

Table 2

Tensile strength		Retained austenite
MPa	Ksi	%
1780-2010	258-291	0-17.5