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Martin Mueller
Sandvik Materials Technology

Gustaf Zetterholm
Sandvik Materials Technology

Guocai Chai
Sandvik Materials Technology

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INFLUENCE OF MATERIAL ORIENTATION ON THE FATIGUE PROPERTIES OF FLAPPER VALVES

Martin MUELLER[1], Gustaf ZETTERHOLM[2] and Guocai CHAI[3]*

[1]Sandvik Materials technology, Strip, 811 81 SANDVIKEN, SE-Sweden
(tel: +46 26 264062, fax: +46 26 260254, email: martin.muller@sandvik.com)

[2, 3]Sandvik Materials technology, R&D, 811 81 SANDVIKEN, SE-Sweden
[2](tel: +46 26 264424, fax: +46 26 257140, email: gustaf.zetterholm@sandvik.com)
[3](tel: +46 26 263534, fax: +46 26 257140, email: guocai.chai@sandvik.com)

ABSTRACT

A flapper valve may consist of several tongues with different orientations. These tongues suffer from similar cyclic impact and bending stresses simultaneously during service. For flapper valve design, it is therefore important to know the mechanical properties, especially bending fatigue strength and impact fatigue strength, of flapper valve strips in all orientations. This paper is a study of the influence of specimen (or tongue) orientations on the mechanical properties of one martensitic stainless valve steel (modified AISI 420) in the as delivered conditions. The results show that the strip material contains texture that affects both the E-modulus and the tensile strength, but the influences of the specimen orientation on the yield and tensile strength and the hardness are relatively small and less than 5%. Both the bending fatigue strength and impact fatigue strength slightly increases with increasing orientation angles. However, the bending fatigue strength is mainly related to the tensile strength, and the impact fatigue strength is related to both the tensile strength and the E-modulus. At the specimen orientation angle of 90º, a combination of highest bending fatigue strength and highest impact fatigue strength can be obtained. This investigation may provide useful information for flapper valve designers to optimise flapper valves with high performance and reliability.

1. INTRODUCTION

As known, a flapper valve can suffer from repeated bending and impact stresses during its service (Soedel, 1984). The impact and bending fatigue strengths of flapper valve strip materials are, therefore, extremely critical properties for the life of a compressor since the flapper valves are the most critically loaded components. Considerable efforts have been made to obtain flapper valve strip materials with high performance (Olsson, 1992; Auren et al. 2002, Sandvik, 2003, Chai et al. 2004). It was found that to obtain a high bending fatigue strength, flapper valve materials should have both high tensile strength and high ductility. The surface after surface treatments should show a very good finish and high compressive residual stresses with a low stress relaxation rate. A flapper valve steel with high impact fatigue strength should have a high tensile strength, high ductility and high damping capacity (Zetterholm et al. 2006).

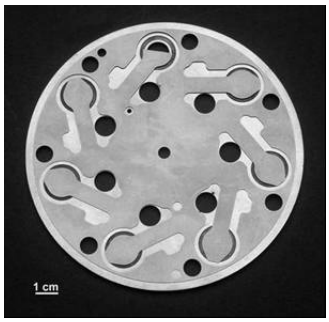

Figure 1: Flapper valve

A flapper valve may consist of several tongues with different orientations (Figure 1). These tongues suffer from similar cyclic impact and bending stresses simultaneously during service. For flapper valve design, it is therefore important to know the mechanical properties, especially the bending and impact fatigue strengths, of flapper valve strips in all orientations since they are the most important properties concerned. This paper is a study of the influence of specimen (or tongue) orientations on the mechanical properties of one martensitic stainless valve steel (modified AISI 420) in the as delivered conditions.

2. MATERIAL AND EXPERIMENTAL

2.1 Material

The material used was a Fe-0.38C-0.4Si-0.55Mn-13.5Cr-1.0Mo (wt%) martensitic stainless flapper valve steel strip material, a modified AISI 420, with a thickness of 0,305mm. The specimens with five orientations: 0º, 30º, 45º, 60º and 90º to the rolling direction were taken from the strip. Figure 2 schematically shows the specimens with different orientations for the bending fatigue and impact fatigue testing.

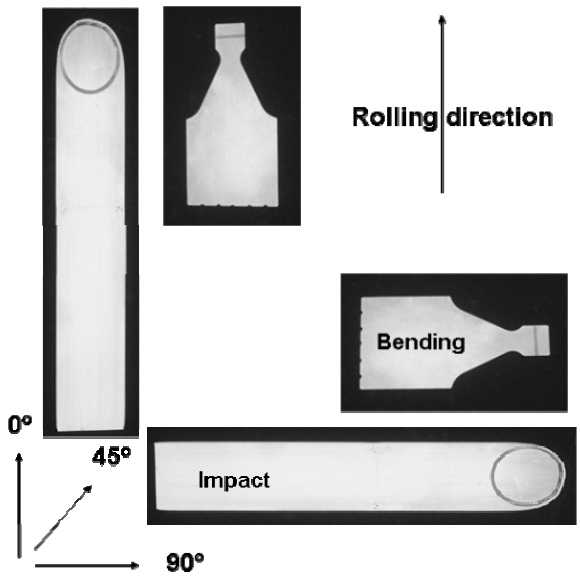

Figure 2: Specimens with different orientations for the bending fatigue and impact fatigue testing

2.2 Experimental

In this investigation, extensive mechanical tests have been performed. The tensile testing was performed using a double test at room temperature, and the hardness was determined with a weight of 100gram using a micro hardness tester.

Two types of fatigue tests, namely reversed bending and impact, were performed in a laboratory environment at room temperature. Reversed bending fatigue test (R=-1) was performed using a Sandvik UMG test machine with a frequency of 25 Hz. Impact fatigue tests were performed using Sandvik Impact Fatigue Tester with a frequency of 250 Hz. The fatigue strength was determined using the staircase method with 50 % fracture probability. The specimen was tested at a given level of a stress until failure or until a maximum of $2 \cdot 10^6$ cycles for reversed bending or $1 \cdot 10^7$ cycles for impact was reached without failure. The impact fatigue strength is the speed at which the specimen hits the seat. S-N curves for these two types of fatigue were also determined. A series of 30 specimens were used for each test.

Residual stresses and texture were measured with an X-ray diffractometer using CrKα radiation. Peak positions of Bragg reflexes were obtained using a pseudo-Voigt peak fitting procedure. The stresses were evaluated with the $\sin^2\psi$ method using a Young's modulus of 210 GPa and a Poisson's ratio of 0.30.

3. RESULTS

3.1 Influence of specimen orientation on the tensile properties

Figure 3 shows a summary of the influence of the specimen orientation on the tensile properties. The influences of the orientations on the strength and hardness show similar tendency and also are small (less than 5%). Both strength and hardness are lower at 30º or 45º than other orientations (Figure 3a and b). The E-modulus shows the similar

tendency as that of the tensile strength and has a minimum value at 45º (Figure 3c). For the elongation, as expected, it shows an opposite tendency to the strength as shown in Figure 3d, which has a lowest value at 90 º (Figure 3d).

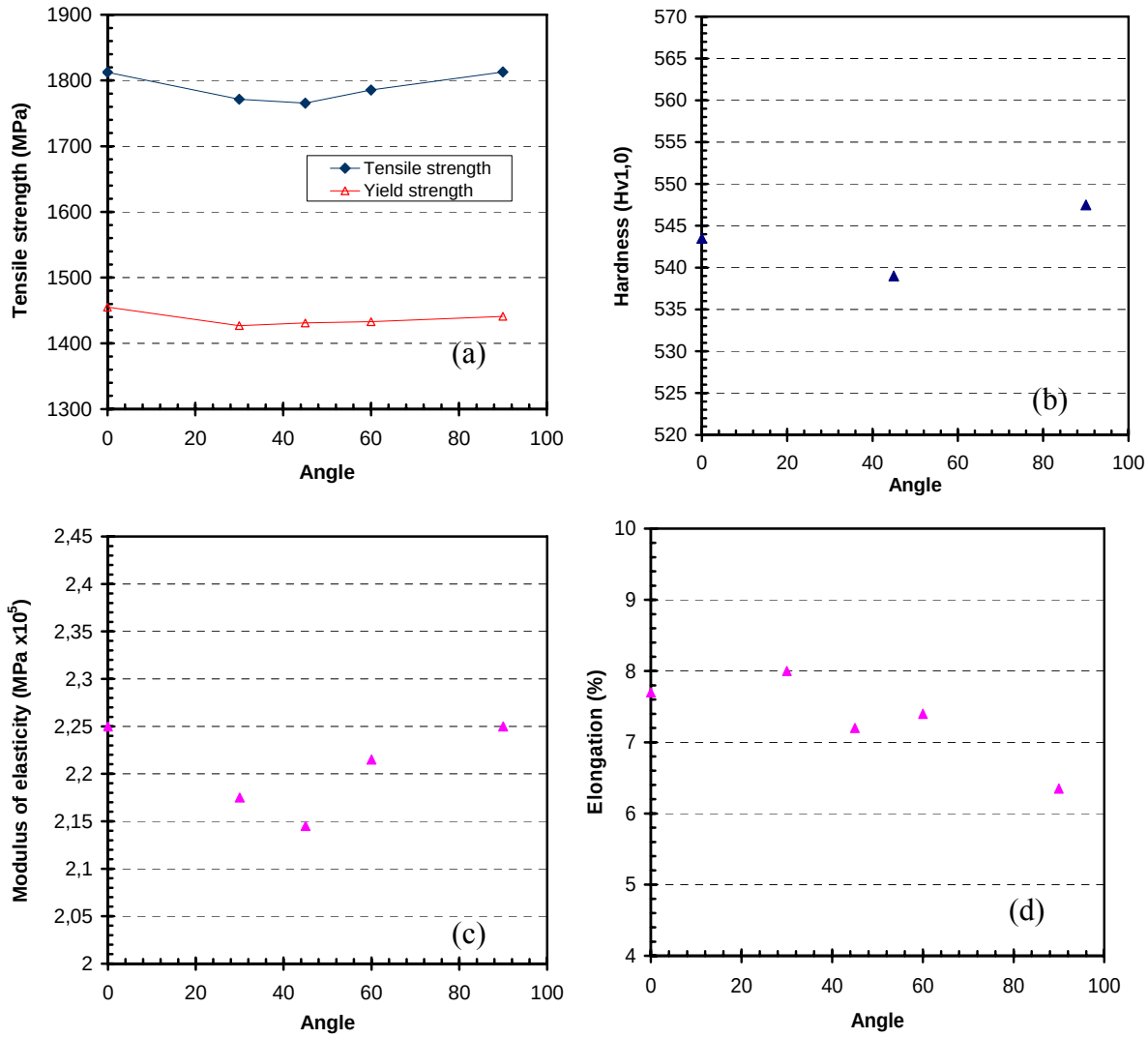

Figure 2: Influence of the specimen orientation on the tensile properties

3.2 Texture

Three pole figures, (110), (200) and (211), and its diffraction intensities have been measured. Two of them are shown in Figure 3. The common strip texture components in cold rolled BCC steels: {100} <011>, {211} <01-1>, {111} <01-1> and {111} <11-2> can be observed in this material. From the (110) pole figure, diffraction intensity from all the above mentioned four texture components can contribute to the spread (110) poles centered at around alfa = 30 degrees. Some of the (110) poles of the {211} <01-1> are located at alfa =30 degrees and some of the {111} <11-2> at alfa = 35 degrees and the others shifted vertically. The {111} <11-2> seems to be stronger, which gives higher intensity of the poles at alfa = 60 degrees in the (200) pole-figure, but it was found that the {211} <01-1> component is weaker from the (211) pole density at alfa = 0, and the higher pole density could mean a stronger {111} <01-1>.

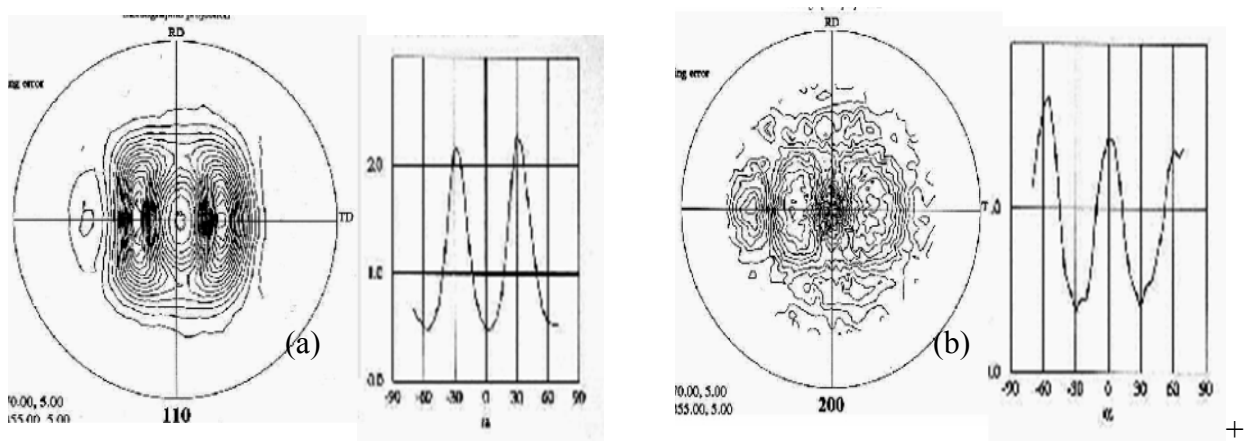

Figure 3: Pole figures and its diffraction intensities

3.3 Influence of specimen orientation on residual stress

Table 1 shows the influence of the specimen orientation on the residual stresses at the strip surface. It can be seen that the residual stress at the specimen with an orientation of 45º is highest, and then decrease with increasing or decreasing orientation angles. The residual stress at 0º is about 20% lower than that at 45º.

Table 1: Influence of specimen orientation on residual stresses

Angle	0	30	45	60	90
Residual stress (MPa)	-527±25	-626±31	-646±32	-589±30	-555±31

3.4 Influence of specimen orientation on fatigue properties

Two types of fatigue properties, S-N curve and fatigue limit, have been investigated. Figure 4 shows one example on the influence of the specimen orientation on the S-N curves of the bending fatigue. It seems that the specimen near the rolling direction (small angle) shows higher fatigue life than that near the transversal direction (big angle) in the high stress range, but it is vice verse in the low stress range. The S-N curves of the impact fatigue of the strip material show the similar tendency, but the scatter of the test results are higher than that of the bending fatigue.

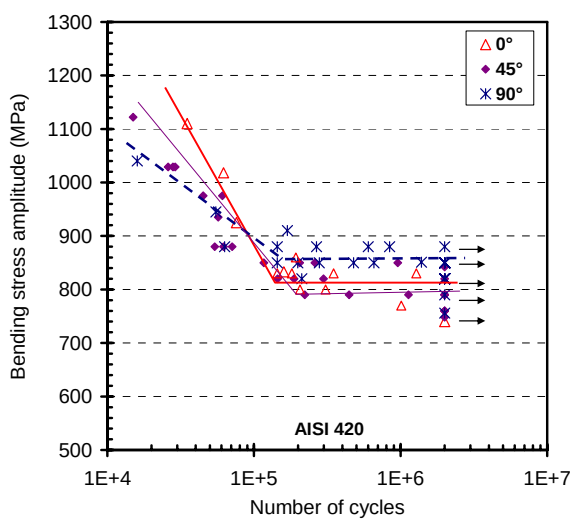

Figure 4: Influence of the specimen orientation on the S-N curves

Table 2 is a summary of the fatigue testing results, and Figure 5 shows the influence of the specimen orientation on the bending and impact fatigue properties. The bending fatigue strength varies from 785MPa to 850MPa (about 8%), and the impact fatigue strength varies from 6,6m/s to 7,4m/s (about 10%) with the specimen orientations. Both bending fatigue strength and impact fatigue strength show a tendency that they slightly increase with the orientation angles, except that the impact fatigue strength has a peak at 45° and the bending fatigue strength has a valley at 30°.

Table 2: Influence of the specimen orientation on the fatigue properties

Angle	Rm	Rp0,2	σ_{ub}_bending	sd	σ_{ub}/Rm	σ_{ui}_impact	sd
	(MPa)	(MPa)	(MPa)	(MPa)		(m/s)	(m/s)
0	1812	1455	810	33	0,45	6,6	0,3
30	1771	1427	785	23	0,44	6,8	0,5
45	1765	1431	799	29	0,45	7,4	0,4
60	1785	1433	837	67	0,47	6,7	0,6
90	1813	1441	850	30	0,47	7,4	0,4

σ_u: fatigue strength, σ_{ub}: bending fatigue strength, σ_{ui}: impact fatigue strength, sd: standard deviation

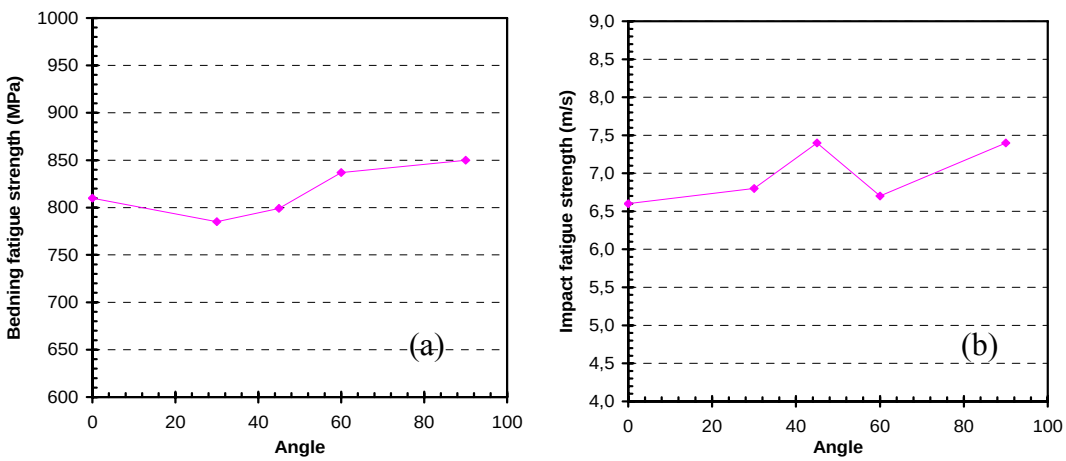

Figure 5: Influence of the specimen orientation on the fatigue strength

4. DISCUSSION

4.1 Influence of texture on the tensile properties

As discussed in 3,2, relatively strong textures {100}<011>, {111}<01-1> and {111}<11-2> exist in this strip material. As known, texture can strongly affect the modulus of elasticity of material, and also cause a texture hardening. Figure 6 is a tensile strength versus E-modulus curve for this strip material. It shows a good correlation. This indicates that the variation of the tensile properties with the specimen orientation is mainly due to the presence of texture in the strip. The higher tensile strengths at 0º and 90° are mainly attributed to the presence of stronger texture.

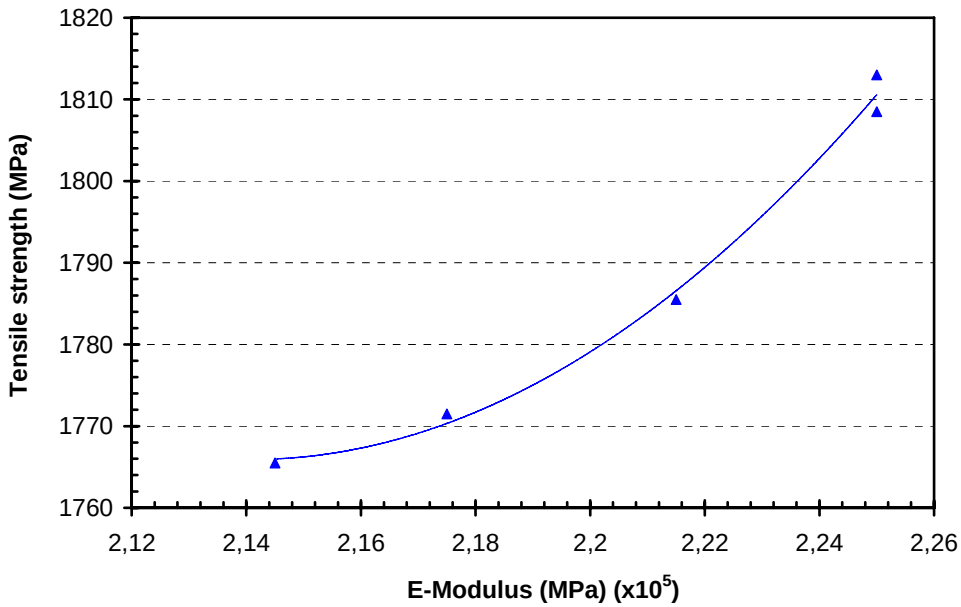

Figure 6: Correlation between the E-modulus and the tensile strength

4.2 Fatigue properties of flapper valve strip with different orientations

Earlier investigations show that the bending fatigue properties of flapper valve are related to a combination of tensile strength and ductility of materials and the surface conditions (Auren et al. 2002, Chai et al. 2004). A flapper valve steel with high bending fatigue strength should have a high tensile strength with high ductility. The surface after surface treatments should show a very good finish and high compressive residual stresses with a low stress relaxation rate. In this investigation, however, it was found that the bending fatigue strength is mainly related to the tensile strength (Figure 7a). The influences of the elongation or ductility and surface residual stresses on the bending fatigue strength are relatively small. This indicates that the influence of the specimen orientation on the bending fatigue strength is mainly due to the texture hardening.

The impact fatigue strength is not related to the tensile strength since it increases with the orientation angles as shown in Figure 5b. The high impact fatigue strengths at 30°, 45° and 60° (comparing with low bending fatigue strength) may be attributed to the high compressive residual stresses (Figure 7b) and the comparatively low E-modulus (Figure 7c). The high impact fatigue strength at 90° may be due to the high tensile strength. The influence of E-modulus on the impact stress can be calculated by equation 1.

$$\sigma_o = v_o \sqrt{E\rho} \qquad (1)$$

where σ_o is the initial stress induced by impacting, v_o is the impact velocity, ρ is the density of the strip, and E is the E-modulus. This equation shows that high initial stresses at the impact area can be created by high impact velocity. Figure 7d shows the influence of E-modulus on the impact initiation stresses at the impact area at given impact velocities. The initial stress increases with increasing E-modulus or the impact velocity. Consequently, a material with high tensile strength and a low E-modulus can lead to a high impact fatigue strength. Since texture can significantly affect E-modulus, it can also affect the impact fatigue strength of the strip. The above discussion leads to a conclusion that at the specimen orientation angle of 90º, a combination of highest bending fatigue strength and highest impact fatigue strength can be obtained.

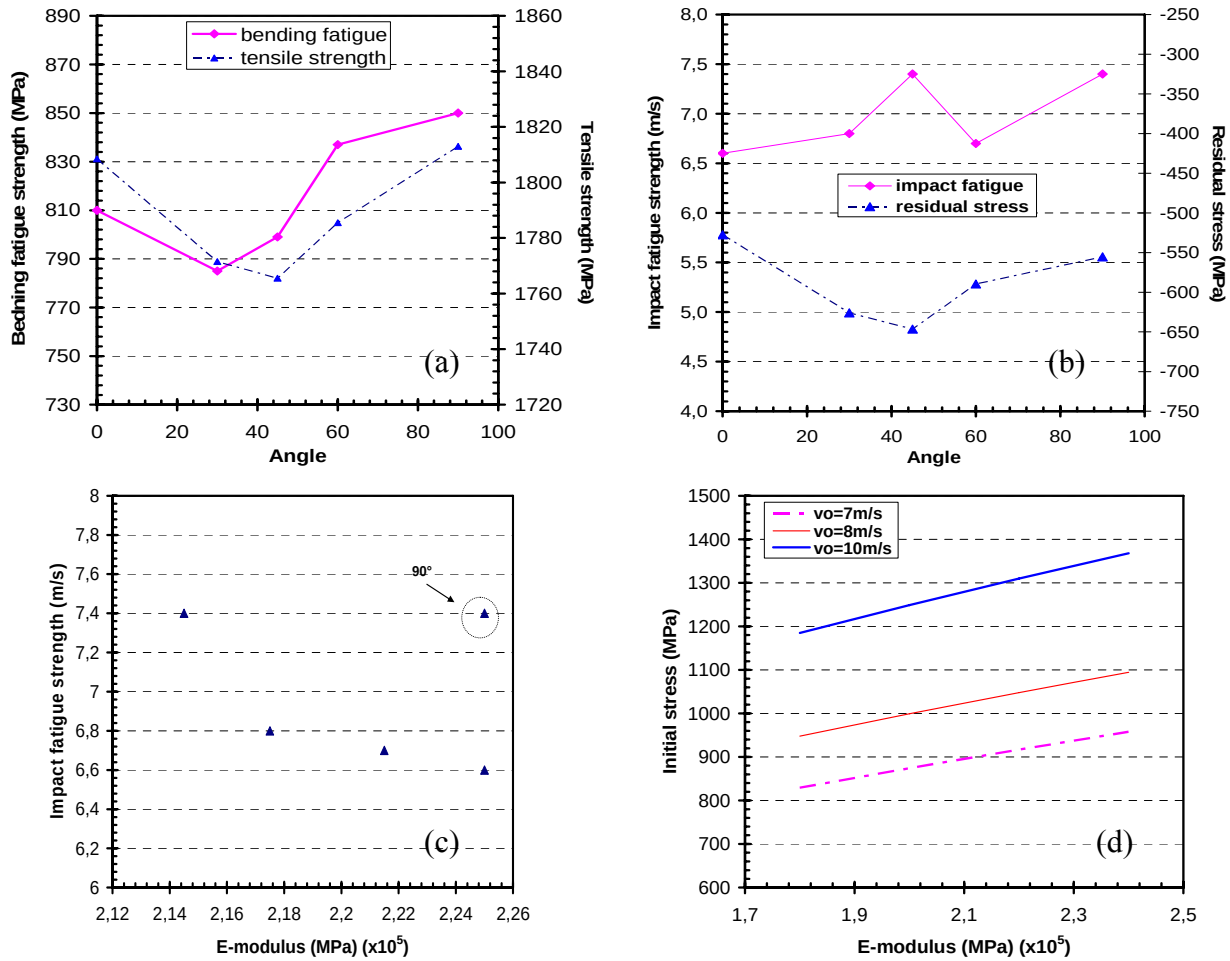

Figure 4: Parameters that affect the fatigue strengths.

5. CONCLUSIONS

The influences of the specimen orientation in a flapper valve strip material: AISI 420 steel on the mechanical properties, especially the bending and impact fatigue strengths, have been investigated. The following conclusions can be obtained.

- The strip material contains texture that affects both the E-modulus and the tensile strength.
- The tensile strength and hardness have somewhat lower values at the orientations of 30° and 45º, but the influences of the specimen orientation on the yield and tensile strengths and the hardness are relatively small and less than 5%.
- Both the bending and impact fatigue strengths show a tendency that they increase with increasing orientation angles. However, the bending fatigue strength is mainly related to the tensile strength, and the impact fatigue strength is related to both the tensile strength and the E-modulus.
- At the specimen orientation angle of 90º, a combination of highest bending fatigue strength and highest impact fatigue strength can be obtained.

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REFERENCES

Zetterholm, G., Mueller, M. and Chai, G., 2006, *Parameters that affect flapper valves with high performance,* ACRA 2006, in Press.

Sandvik Data sheet, 2003, *Strip steel for flapper valves*, S-343-Eng. AB Sandvikens Tryckeri, Sweden.

Soedel, W., 1984. *Design and mechanics of compressor valves*, OFFICE PUBLICATION, Purdue University.

Olsson, S., 1992, Improved characteristics of stainless compressor valve steel, *Inter. Compressor Engineering Conf. at Purdue,* Purdue University, Indiana, USA, No. 3, pp. 909-918,

Chai, G., Zetterholm, G., and Walden, B., 2004, Flapper valve steels with high performance, *Inter. Compressor Engineering Conf. at Purdue,* Purdue University, Indiana, USA, C132.

Auren, B., Chai, G., 2002, Effect of material properties and surface treatment on the performance of stainless flapper valve steel for compressors, *Inter. Compressor Engineering Conf. at Purdue,* Purdue University, Indiana, USA, C13-1.