Selection of flapper valve steel for high efficient compressor

Mathias Hareland

Anders Hoel

Stefan Jonsson

David Liang

Guocai Chai

Outline

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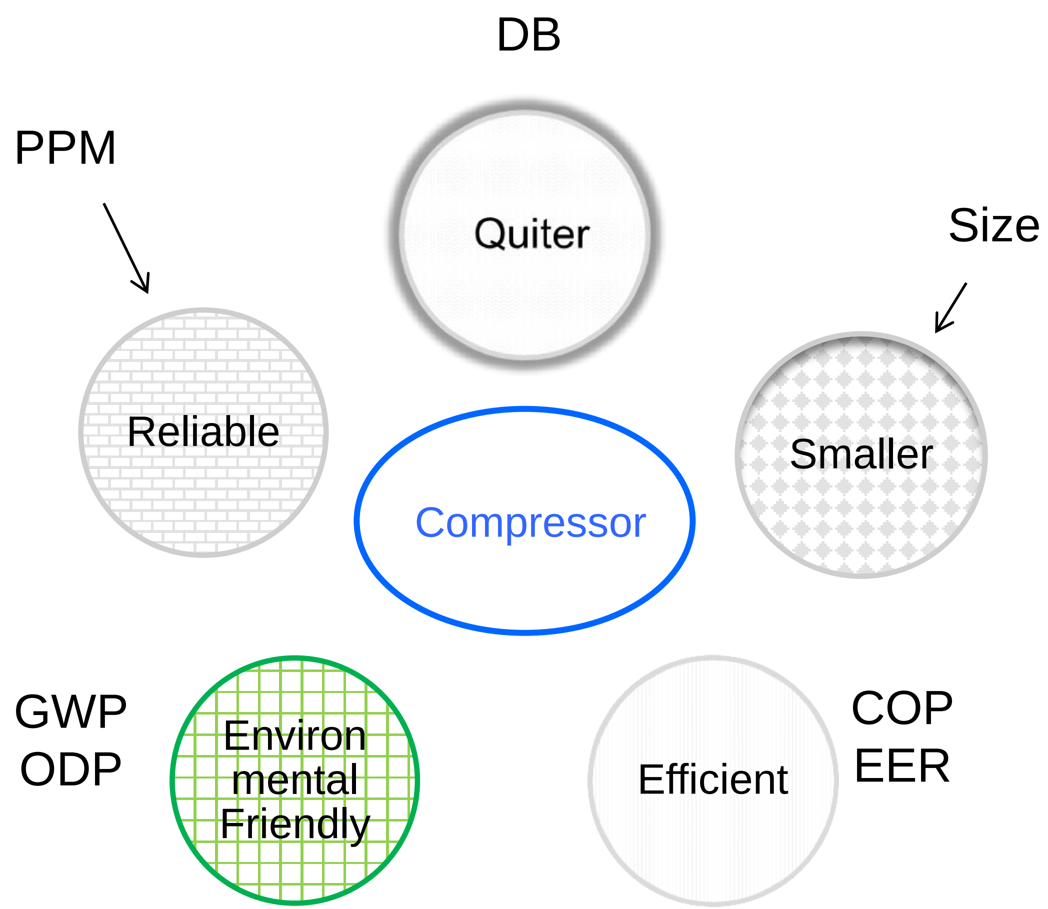
2. Simulation on impact stress
3. Crack initiation and propagation
4. Materials investigation
5. Case studies
6. Conclusions

Selection of flapper vavle steel for high efficient compressor

1. Introduction

Industy and customer demands



Flapper valve requirements

*** Higher pressures**

*** Higher temperature**

*** Higher operating frequency**

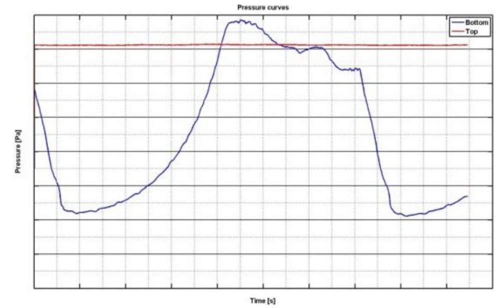
*** Higher discharge volume**

*** Higher valve lift**

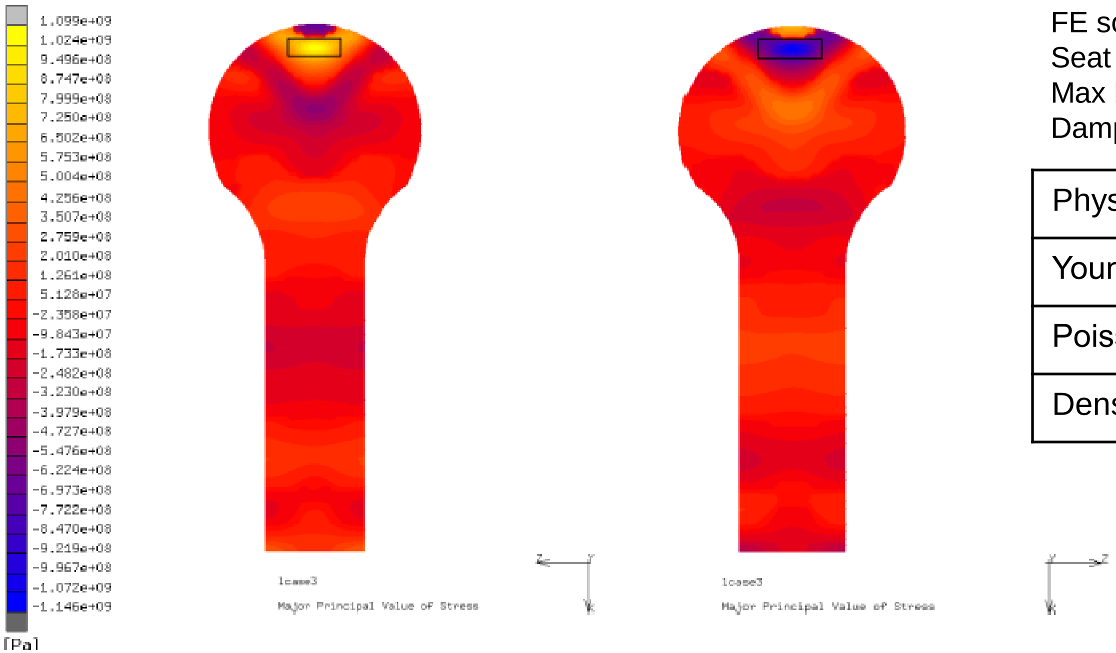
*** Reduced thickness**

*** Reduced valve length**

2. Simulation of impact stress



Top   Bottom

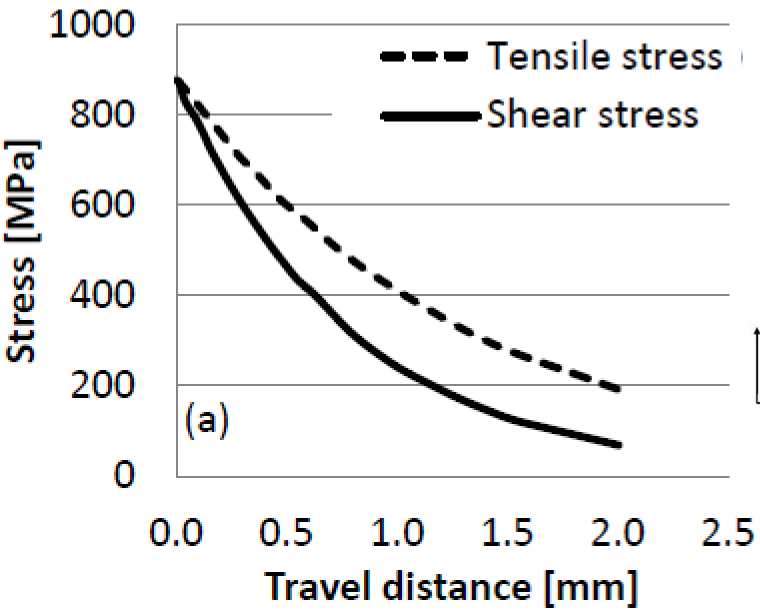


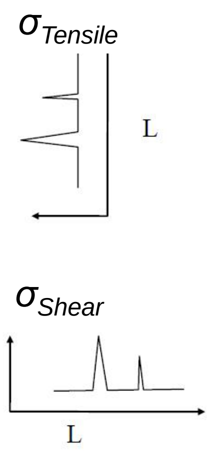
FE software MSC. Marc 2011r1
Seat of cast iron (E – modulus 130 GPa)
Max bending stress 260 MPa
Damping not included

Physical property	Value
Young's modulus, E [GPa]	210
Poisson's ratio, ν	0.3
Density, ρ [kg/m^3]	7700

At 7.8 m/s
Max stress level:
Top 1099 MPa
Bottom -1146 MPa

3. Crack initiation and propagation





$$\sigma = \sigma_0 e^{-(\frac{tA\sqrt{E\rho}}{m})} where\ t = \frac{L}{C_i}$$

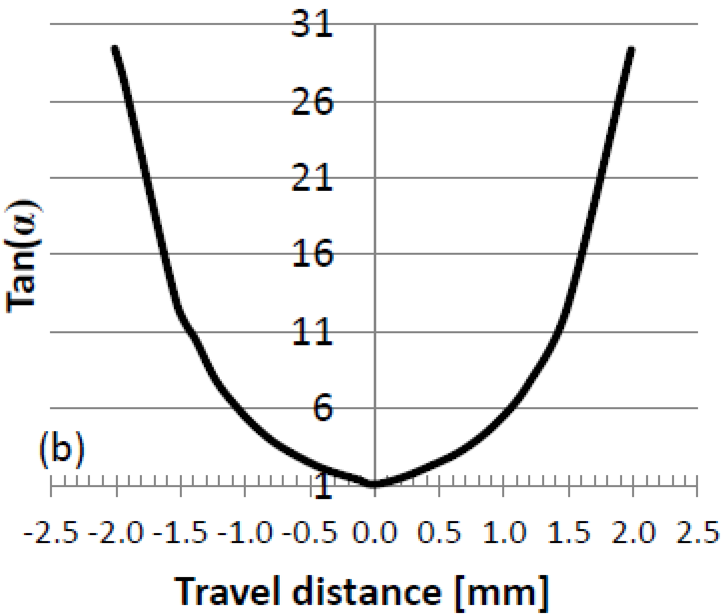
$$C_1 = \sqrt{E/\rho} \quad C_2 = \sqrt{G/\rho}\ where\ G = \frac{E}{2(1+v)}$$

$$\sigma = \sigma_0 e^{-\frac{LA\sqrt{E\rho}}{mC_i}}$$

$$Tan(\alpha) = \frac{\sigma_{Tensile}}{\sigma_{Shear}}$$

σ	*damped impact stress*
σ_0	*undamped stress*
t	*travel time*
A	*Impact area*
M	*mass of material*
ρ	*density*
E	*Elasticity modulus*
G	*Shear modulus*
v	*Poissons ratio*
L	*wave travel distance*
C_1	*Tensile wave velocities*
C_2	*Shear wave velocities*

3. Crack initiation and propagation



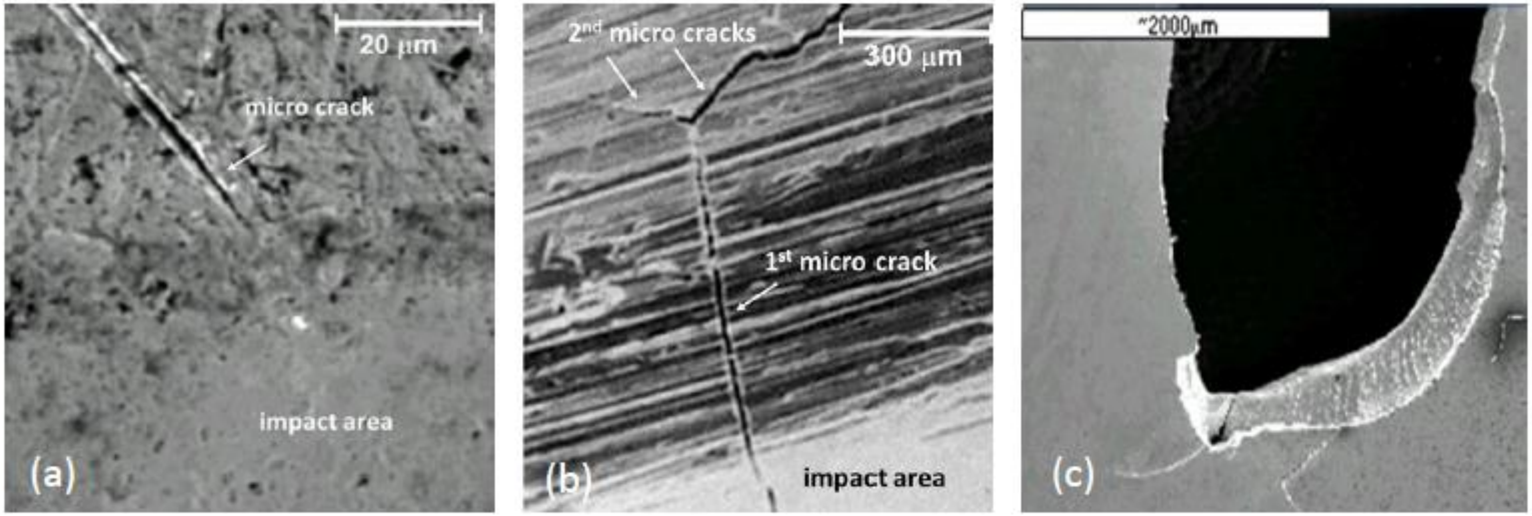
$$\sigma_{Tensile} = \sigma_0 e^{-\frac{LA\rho}{m}}$$

$$\sigma_{Shear} = \sigma_0 e^{-\frac{LA\rho}{m} * 2(1+v)}$$

$$Tan(\alpha) = \frac{\sigma_{Tensile}}{\sigma_{Shear}}$$

3. Crack initiation and propagation

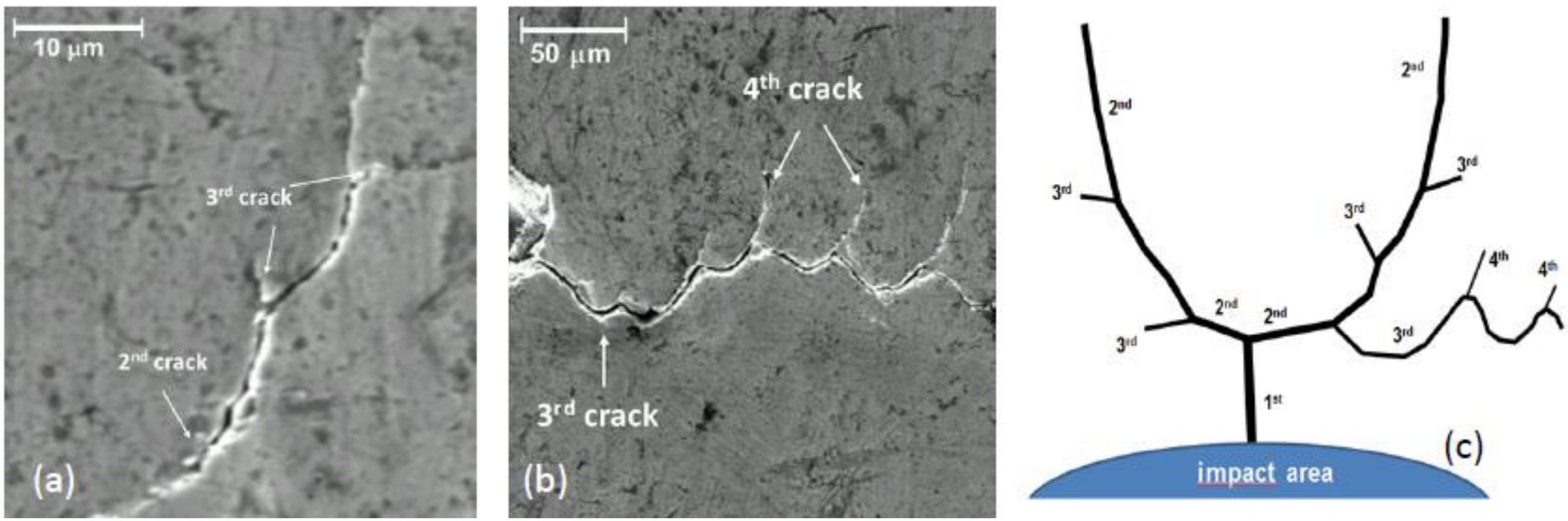
Fatigue crack initiation and propagation during impact



a) Crack initiation
b) Splitting of main crack
c) Formation of chipping

3. Crack initiation and propagation

Fatigue crack initiation and propagation during impact



a) Along radial direction
b) Along transversal direction
c) A fracture model based on dynamic stress wave theory

3. Crack initiation and propagation

This analysis indicates that a material with high impact fatigue strength should have:

1). High resistance to crack initiations and propagations by repeated impact loading
2). High stress decay rate to stress wave travelling so that the crack propagation becomes difficult.

4. Materials investigation

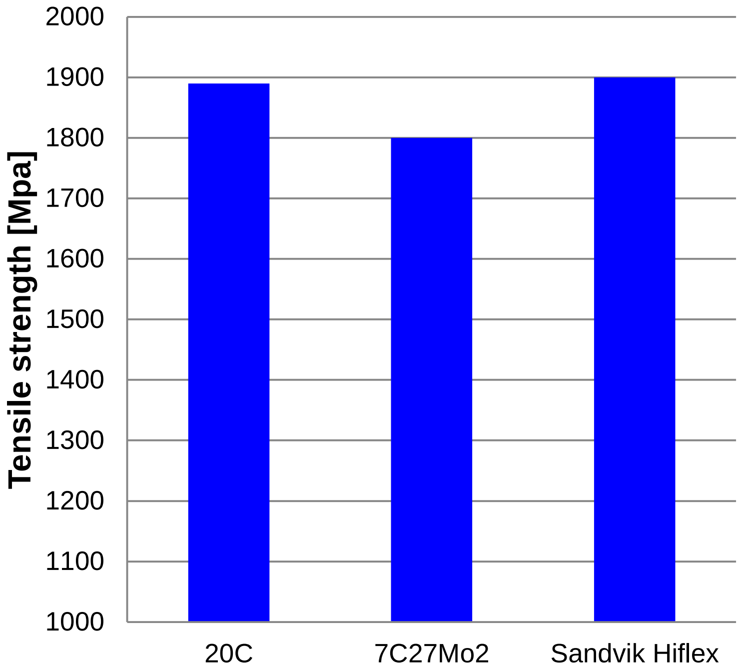
Investigation of 3 different flapper valve steels materials

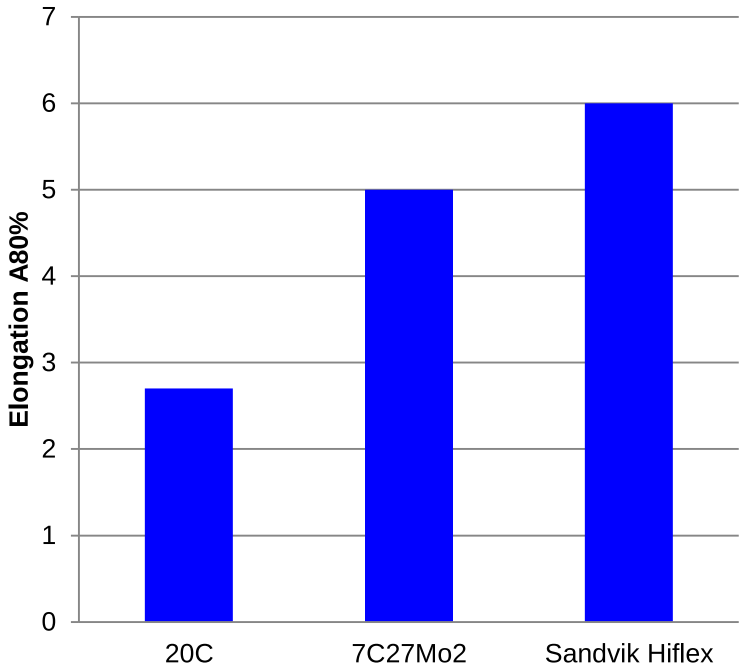
Sandvik 20 C	AISI 1095
Sandvik 7C27Mo2	mod AISI 420

and

Sandvik Hiflex™	(which is a type of modified AISI 420 material)

4. Materials investigation

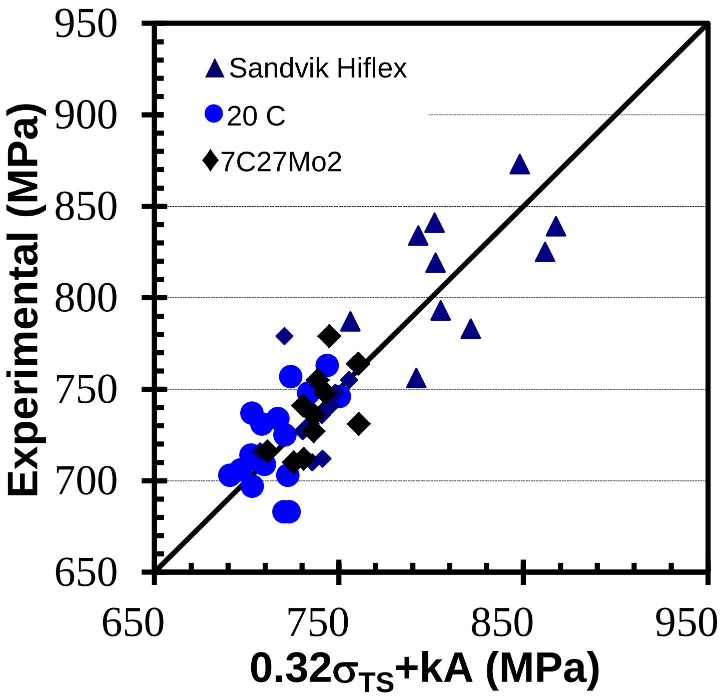




Hiflex has a higher tensile strength but also elongation than the other investigated materials

4. Materials investigation

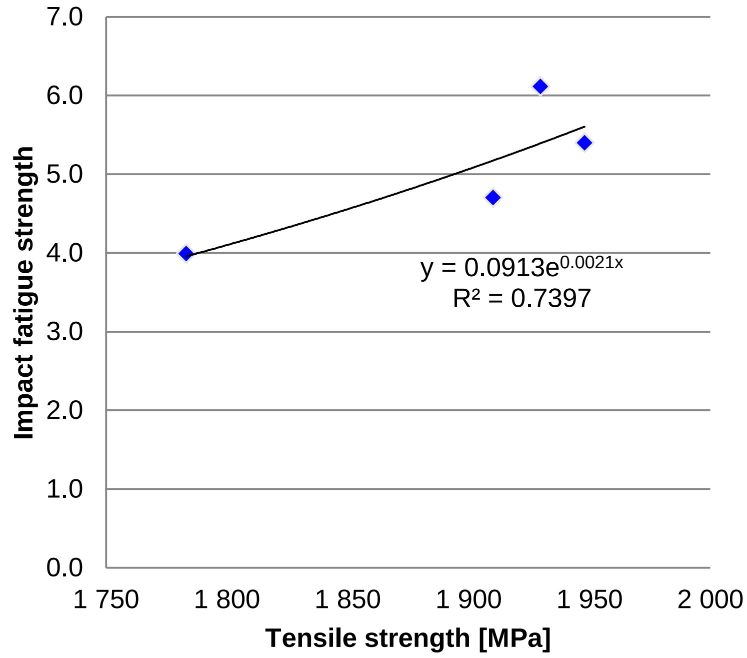
Bending fatigue vs tensile strength σ_{TS} and ductility/elongation A



K is a constant between 18.8 and 25.1 depending on material.

4. Materials investigation

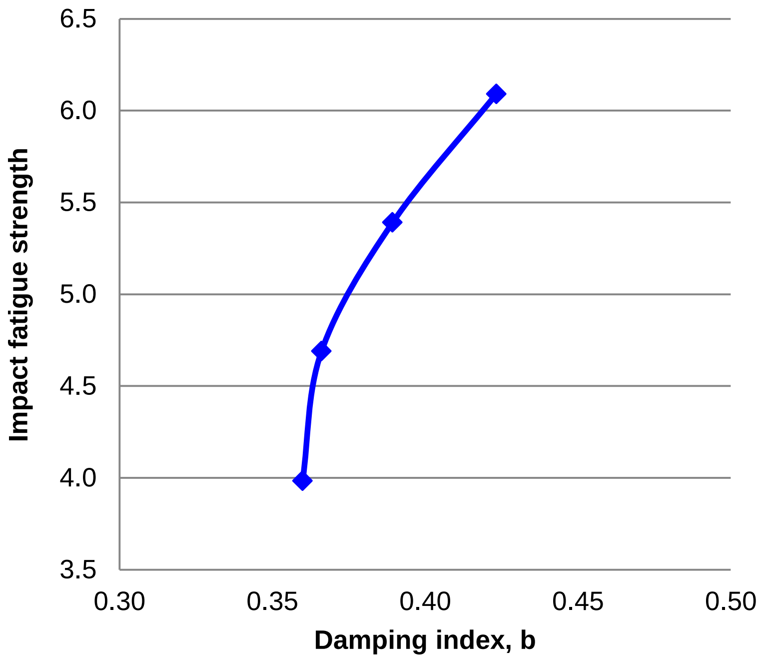
Impact fatigue vs tensile strength



A weak correlation between impact fatigue and tensile strength.

4. Materials investigation

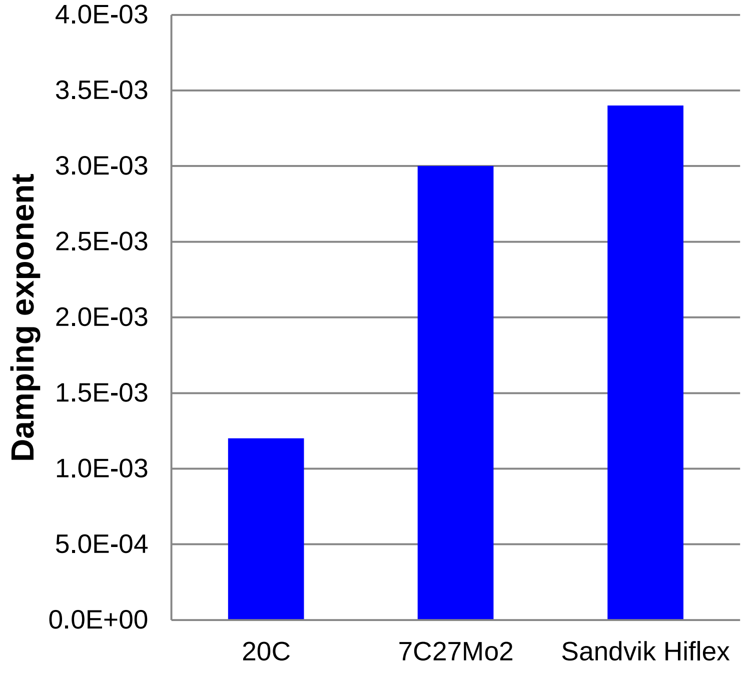
Material with similar
E – modulus
Density
But
different damping capacity



$$A = A_0 e^{-bt}$$

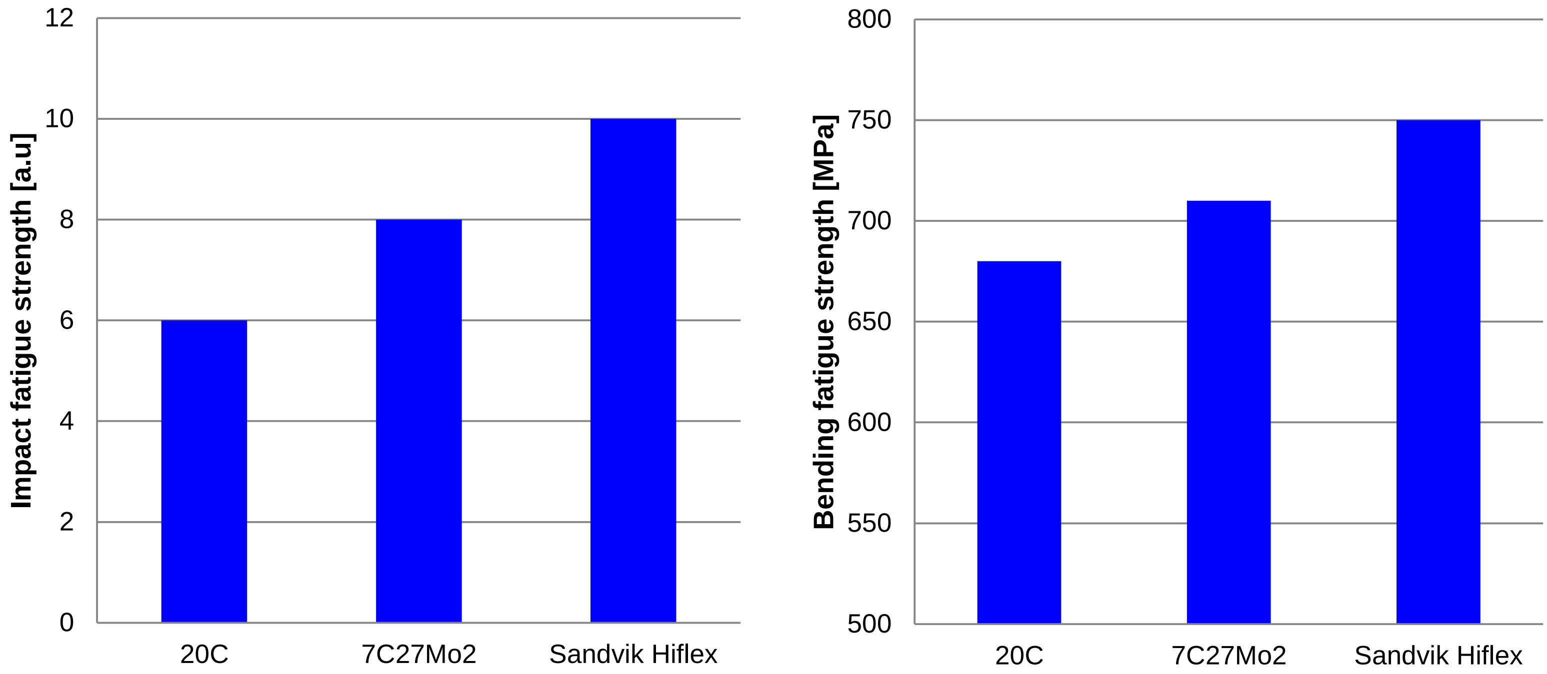
A higher damping index may result in a higher impact fatigue limit

4. Materials investigation



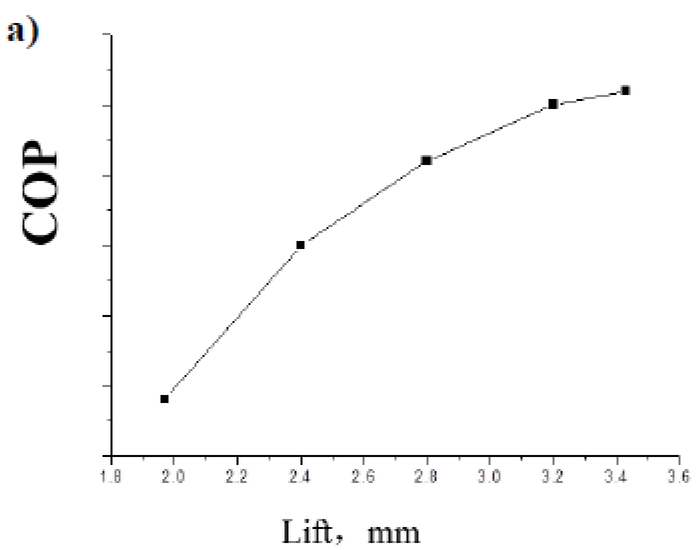
The damping exponent for the different flapper valve steels

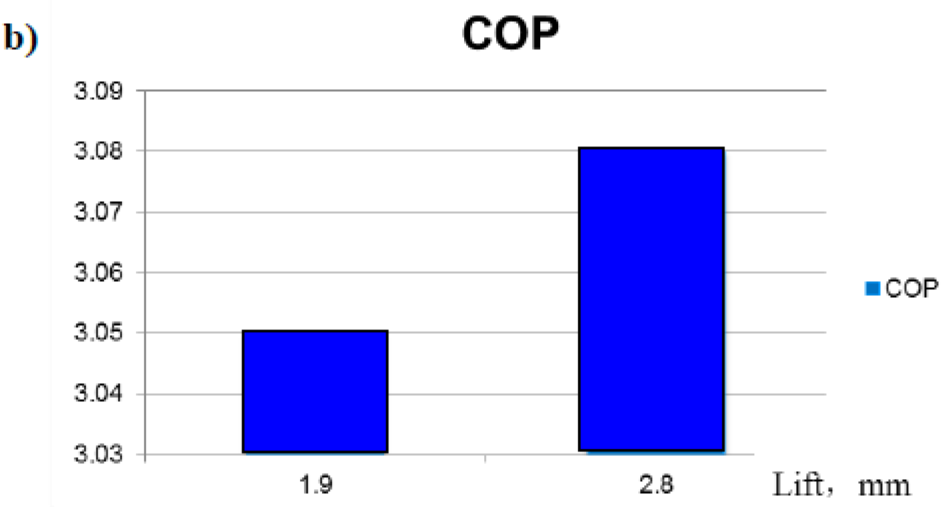
4. Materials investigation



Hiflex exhibit a higher impact fatigue strength and bending fatigue strength than the other investigated materials

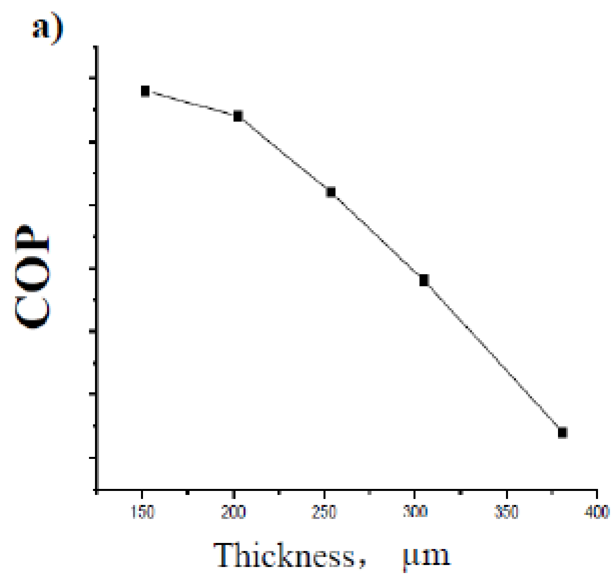
5. Case studies

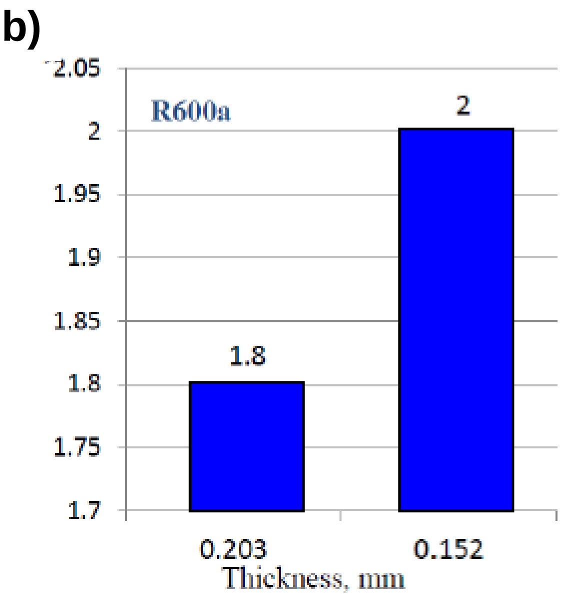




a) COP as a function of valve lift
b) Specifically values on COP for 1.9 and 2.8 mm valve lift in a refrigerant of R22 at a compressor manufacturer

5. Case studies



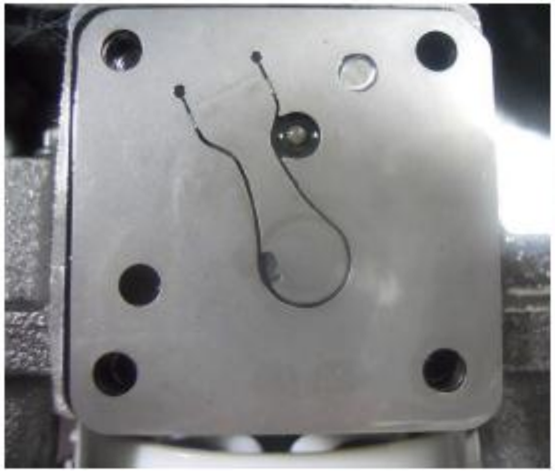


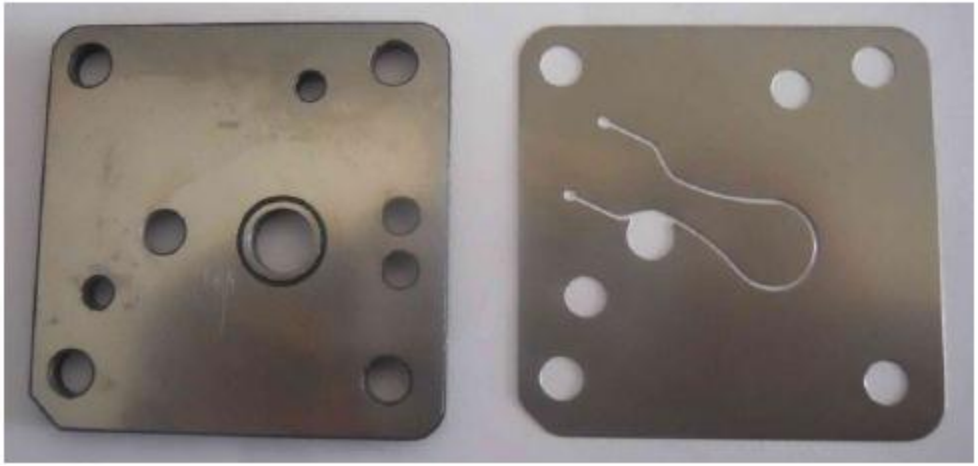
a) COP as a function of valve thickness

Specifically values on (at compressor manufacturer)

b) COP for 0.203 mm and 0.152 mm in a refrigerant of R600a

5. Case studies





Examples of
a) A failed 7C27Mo2 valve
b) A well – functioning valve of Sandvik Hiflex together with seat

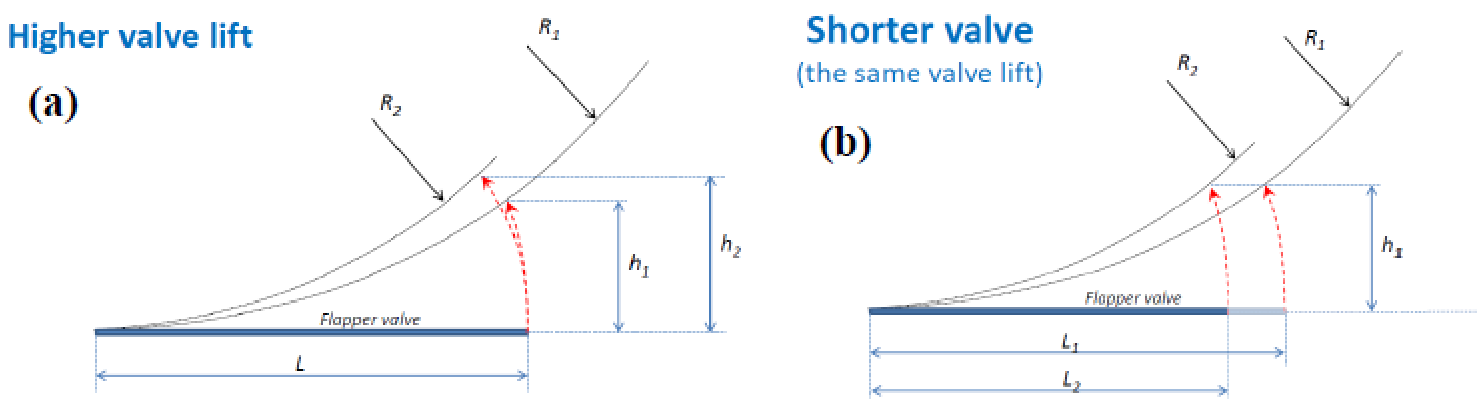
Selection of flapper vavle steel for high efficient compressor

5. Case studies

Refrigerant: R410a		
P_d P_s	3.40 MPa 0.55 MPa	3.40 MPa 0.55 MPa
Operating frequency	120 Hz	180 Hz
Discharge volume	80 cc	80 cc

An example of usage of 7C27Mo2 to tough conditions. When replaced with Sandvik Hiflex the valve menaged the test.

5. Case studies



The higher impact and bending fatigue limits of Sandvik Hiflex lead to improved design freedom due to the following

* Higher valve lift
* Reduced thickness
- Reduced valve length
- Higher damping

6. Conlusions

The stresses that cause the fatigue damage or fracture are the tensile stress wave and shear stress wave induced by repeated impact loading.

- Due to combined stress waves, initiated micro-cracks propagate in waveforms in the transversal direction, and new cracks will initiate at the stress concentration peaks of the original crack. The propagation of new cracks in radial directions leads to edge chipping.

- The crack formation and propagation analysis indicate that a flapper valve material with high performance or fatigue strength should have;
  - high resistance to crack initiations and propagations, by high tensile strength and high ductility
  - high stress decay rate with stress wave travelling so that the crack propagation becomes difficult.

- Sandvik Hiflex™ shows high tensile strength, high bending and impact fatigue strength and high damping capacity, which shows excellent performance in the newly developed high efficient compressors.

Thank you
for
your
attention