PHOENIX LTD
SHIP & ENGINE EQUIPMENT AGENTS

MDL
MACHINE DESIGN LABORATORY NTUA

Comparative Study and Evaluation of Spare Parts for Naval Applications

Short Summary on Materials Testing and Analysis

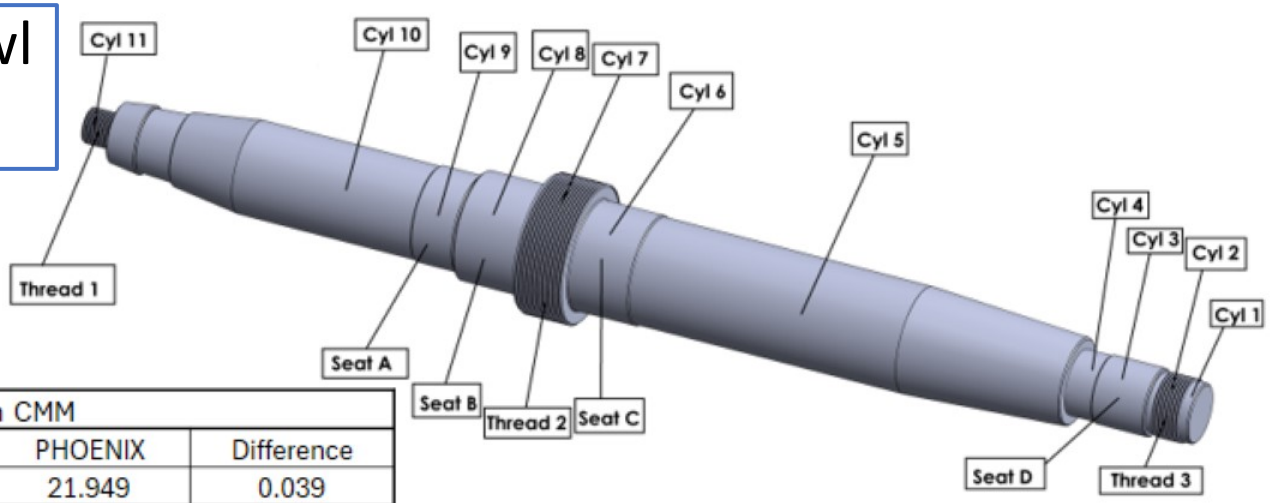
Parts that were analyzed

Material	Name	Part No.
Steel Parts	Bowl Spindle	560134-01
Polymer Parts	O-Rings	9812
		21416
		22864
	Rectangular Ring	13394
Composite Parts	Belt	21411

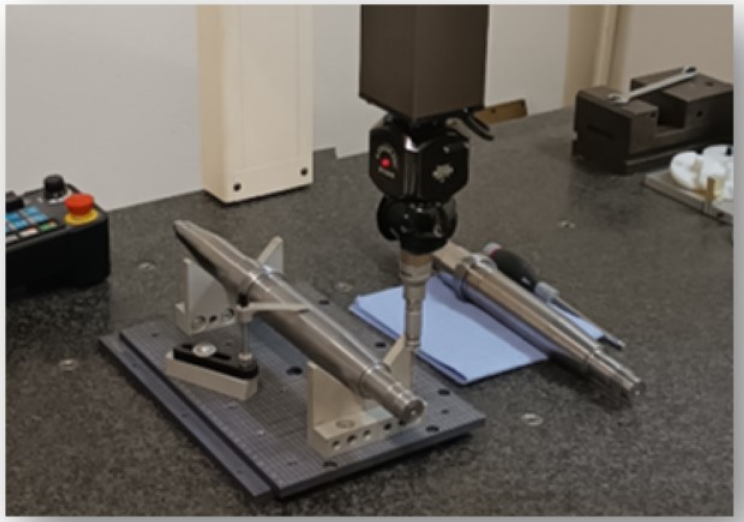
Measurements performed during the study

Components	Parts No.	No. of Samples	Analyzed Properties/Measurements	
			Geometrical	Mechanical
Bowl Spindle	560134 - 01	2	**- Bearing Seats - General Tolerancing**	**Vickers Hardness**
O-rings	9812	2	-	**Tensile Strength**
	21416	2	-	**Tensile Strength**
	22864	2	-	**Tensile Strength**
Rectangular Ring	13394	2	-	**Tensile Strength**
Belt	21411	2	-	**Tensile Strength**
Belt	21411	2	-	**Optical Microscopy**

Measurements of Bowl Spindle using CMM

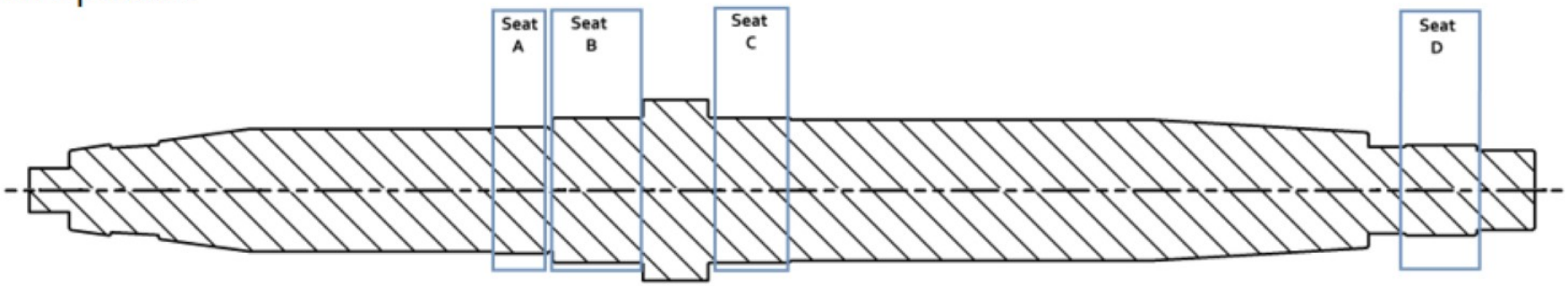


	Measurements from CMM			
	Dimensions in mm	Reference	PHOENIX	Difference
-	Cylinder 1	21.988	21.949	0.039
	Cylindricity 1	0.002	0.004	0.002
Thread 3	Cylinder 2 Thread	24.714	24.784	0.070
Seat D	Cylinder 3	25.011	25.017	0.006
	Cylindricity 3	0.002	0.004	0.002
-	Cylinder 4	23.988	24.409	0.421
	Cylindricity 4	0.003	0.003	0.000
-	Cylinder 5	38.952	38.903	0.049
	Cylindricity 5	0.005	0.005	0.000
Seat C	Cylinder 6	40.007	40.018	0.011
	Cylindricity 6	0.003	0.003	0.000
Thread 2	Cylinder 7 Thread	49.929	49.719	0.210
Seat B	Cylinder 8	39.994	39.967	0.027
	Cylindricity 8	0.003	0.004	0.000
Seat A	Cylinder 9	34.986	34.958	0.028
	Cylindricity 9	0.002	0.002	0.000
-	Cylinder 10	34.002	33.936	0.066
	Cylindricity 10	0.002	0.003	0.001
Thread 1	Cylinder 11 Thread	11.846	11.766	0.080



Dimensional Tolerancing of Bowl Spindle 560134 - 01

Bowl Spindle:



Main Focus : Bearing Seats A, B, C, D

Comparative analysis: PHOENIX vs Reference Bowl Spindle:

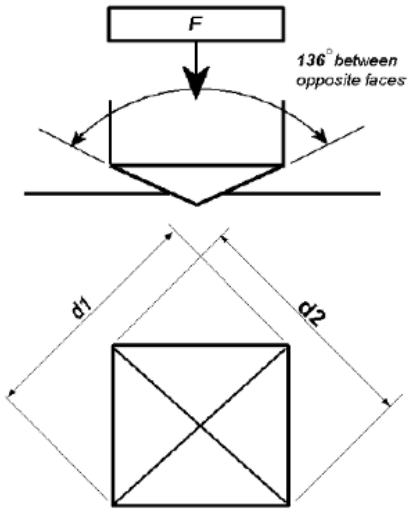
Critical features: Bearing Seats

- PHOENIX spindle **diameter deviations** relative to the reference are **within ±0.03 mm**, matching nominal values on all 4 bearing seats.
- Measured **cylindricity** errors for the PHOENIX spindle are **≤ 0.002 mm**, equivalent to those of the reference spindle and well below functional limits.

Overall assessment

- All critical dimensional and geometrical parameters of the PHOENIX bowl spindle fall within the same tolerance bands as the reference spindle, demonstrating **equivalent precision** and **technical parity**. The only substantial deviation is observed in the diameter of CYL 4, which is not a critical functional feature.

Hardness Analysis by Vickers Indentation on Bowl Spindle



$$HV = \frac{2F\sin\frac{136^o}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

F= Load in kgf

d = Arithmetic mean of the two diagonals,

$d1$ and $d2$ in mm

HV = Vickers hardness

Table: Surface Vickers Hardness on bearing seat C

	D 1 (μm)	D 2 (μm)	F (kgf)	HV
Reference	43	40	0.370	398.3
Phoenix	45	43	0.370	354.32

Vickers Hardness Analysis:

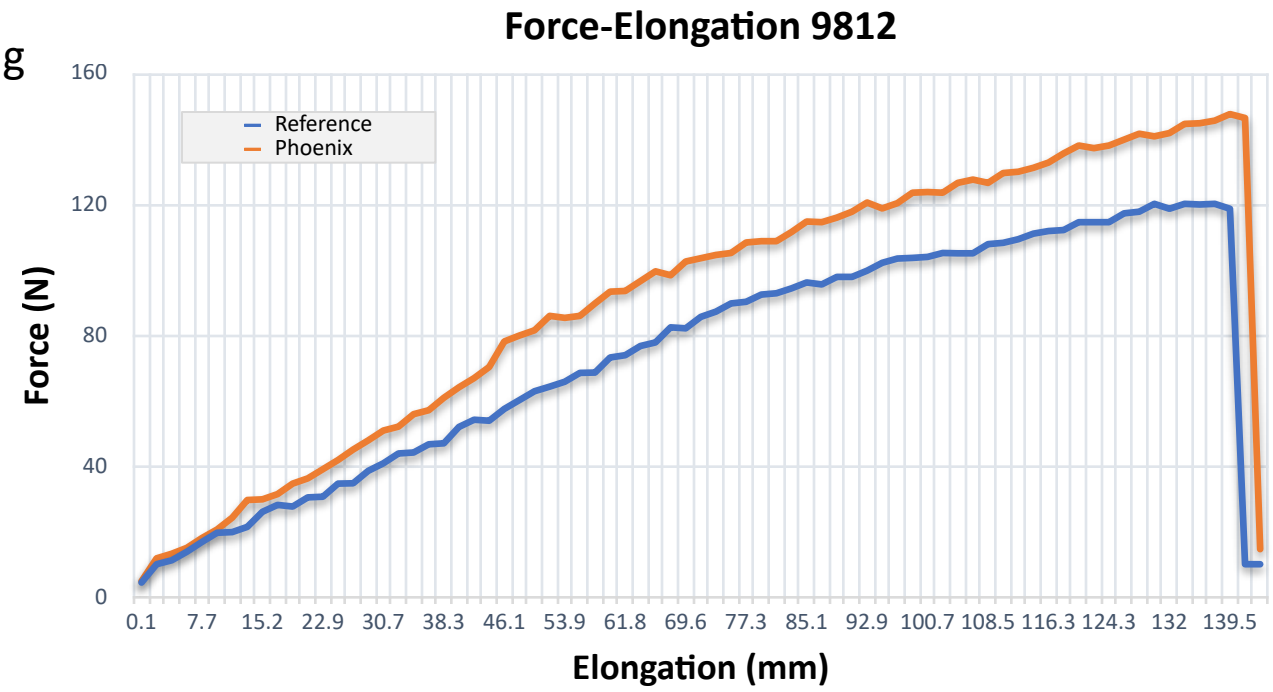
➢ Overall comparable hardness values, but higher for Reference Bowl Spindle

✓ The surface of Phoenix can be improved by surface heat treatment

Mechanical Properties of 9812 O-rings

Load-displacement diagram of tensile tests on 9812 O-ring

➢ Load-Displacement curve



Tensile test results:

- ➢ Higher Maximum Load for Phoenix
- ➢ Higher Maximum Elongation for Phoenix
- ➢ Similar stiffness for both parts

Conclusions:

- ➢ Phoenix O-ring achieves **higher strength** (~20%) and absorbs **higher deformation energy** (~40%)

Note: Statistical accuracy is not given due to low number of test specimens

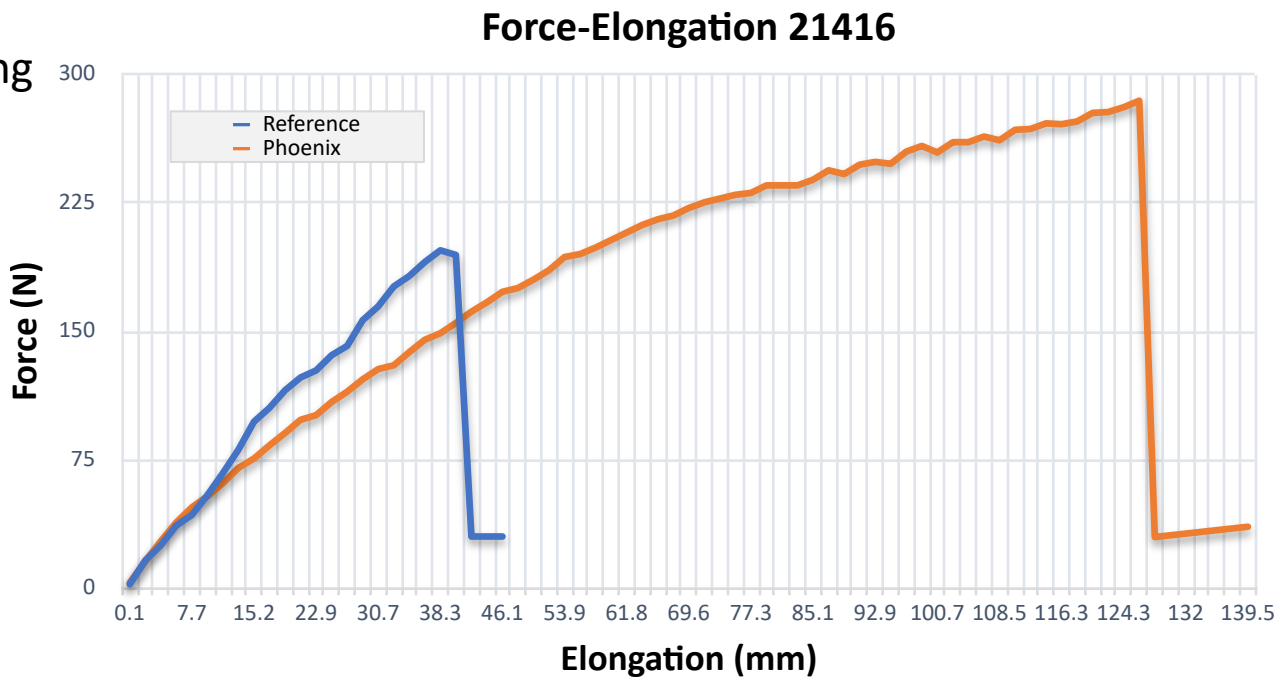
Table: Results of tensile tests on Phoenix o-ring and Reference o-ring according to DIN 53504

spec. no.	Maximum Load (N)	Load at 20 mm (N)	Load at 40 mm (N)	Load at 60 mm (N)	Load at 80 mm (N)	Load at 100 mm (N)	Load at 120 mm (N)	Load at 140 mm (N)	Remarks
Phoenix	146	35	64,2	93	108	124	138	146	max. elongation 143 mm
Reference	121	34,8	60,3	85,7	104	115	-	-	max. elongation 115 mm

Mechanical Properties of 21416 O-rings

Load-displacement diagram of tensile tests on 21416 O-ring

➢ Load-Displacement curve



Tensile test results:

- ➢ Higher Maximum Load for Phoenix
- ➢ Substantially higher Maximum Elongation for Phoenix
- ➢ Slightly lower stiffness for Phoenix

Conclusions:

- ➢ Phoenix O-ring appears **more flexible**, achieving **higher elongation and strength**
- ➢ The substantial difference between the parts may be due to **a defective reference part**

Note: Statistical accuracy is not given due to low number of test specimens

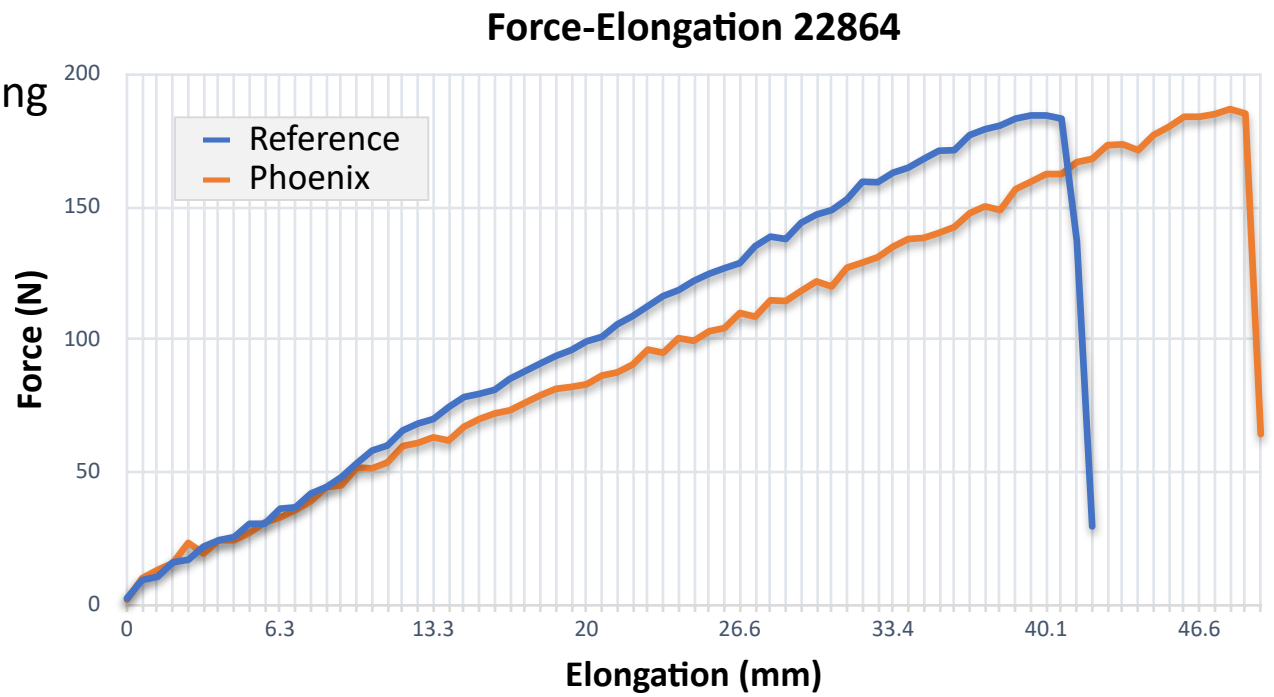
Table: Results of tensile tests on Phoenix o-ring and Reference o-ring according to DIN 53504

spec. no.	Maximum Load (N)	Load at 10 mm (N)	Load at 20 mm (N)	Load at 25 mm (N)	Load at 50 mm (N)	Load at 85 mm (N)	Remarks
Phoenix	284,6	75,8	128	145,1	227,5	280,6	max. elongation 128 mm
Reference	197,3	80	140	180	-	-	max. elongation 41 mm

Mechanical Properties of 22864 O-rings

Load-displacement diagram of tensile tests on 22864 O-ring

➢ Load-Displacement curve



Tensile test results:

- ➢ Higher Maximum Elongation for Phoenix
- ➢ Similar Maximum Load for both parts
- ➢ Similar stiffness for both parts

Conclusions:

- ➢ Phoenix O-ring achieves **similar strength** and shows **slightly higher flexibility** (lower stiffness)

Note: Statistical accuracy is not given due to low number of test specimens

Table: Results of tensile tests on Phoenix o-ring and Reference o-ring according to DIN 53504

spec. no.	Maximum Load (N)	Load at 10 mm (N)	Load at 20 mm (N)	Load at 30 mm (N)	Load at 40 mm (N)	Load at 45 mm (N)	Remarks
Phoenix	175	51,4	83,1	120	162,4	180	max. elongation 49 mm
Reference	184,5	58,1	101	147,1	184,5	-	max. elongation 42 mm

Mechanical Properties of 13394 Rectangular Rings

Load-displacement diagram of tensile tests on 13394 Rectangular Ring

➢ Load-Displacement curve

Tensile test results:

- ➢ **10 Times** Higher Maximum Elongation for Phoenix
- ➢ Slightly lower Maximum Load for Phoenix
- ➢ Lower stiffness for Phoenix
- ➢ Reference part was **defective** with at least 3 defects (air pockets)

Conclusions:

- ➢ Phoenix Rectangular Ring achieves **higher flexibility** (lower stiffness) and **significantly higher elongation** at break and absorbs **significantly higher deformation energy** (~900%)
- ➢ Phoenix rectangular Ring is **more reliable** due to lack of defects and very stable strength profile in its rectangular deformation zone

Note: Statistical accuracy is not given due to low number of test specimens

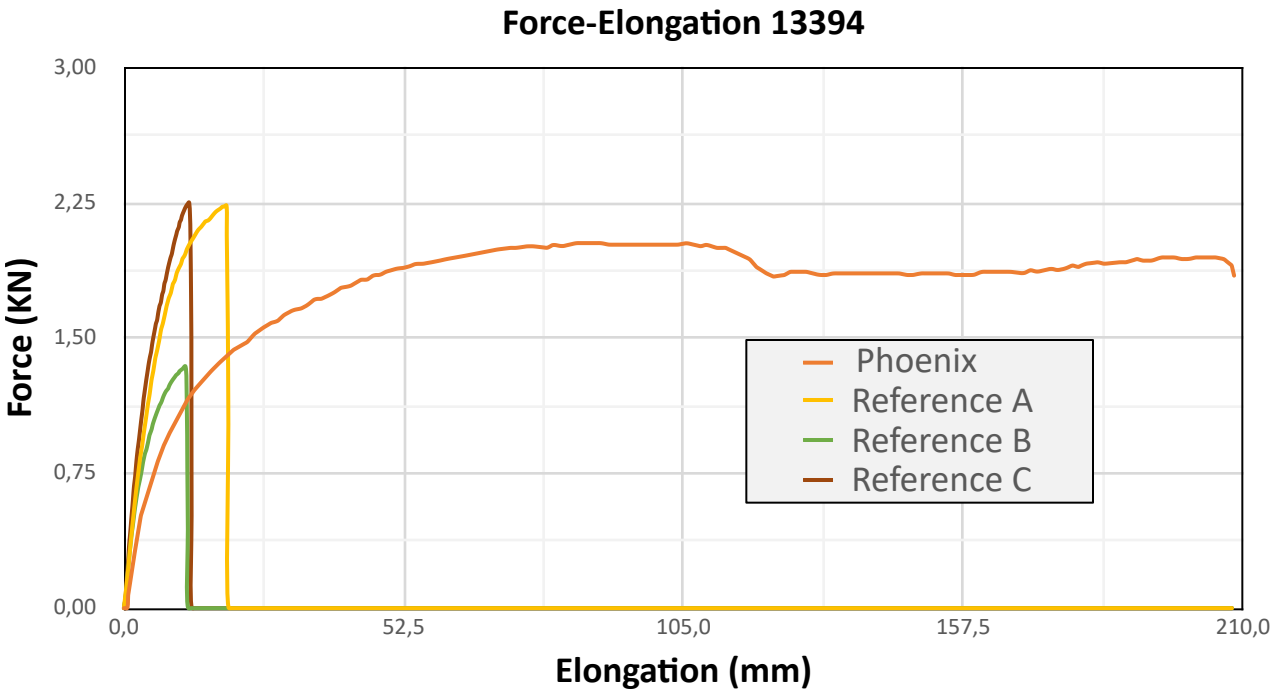


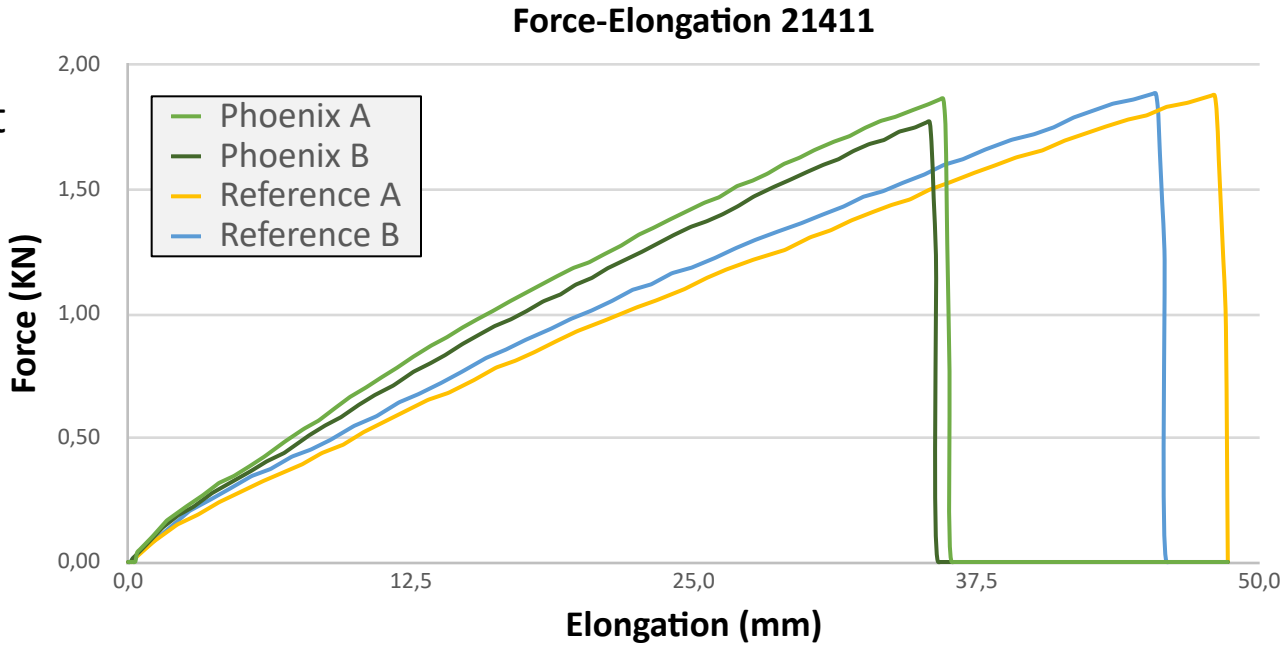
Table: Results of tensile tests on Phoenix Rectangular ring and Reference Rectangular ring according to DIN 53504

spec. no.	Maximum Load (KN)	Load at 10 mm (KN)	Load at 19 mm (KN)	Load at 30 mm (KN)	Load at 50 mm (KN)	Load at 100 mm (KN)	Load at 150 mm (KN)	Load at 200 mm (KN)	Remarks
Phoenix	2.03	1.05	1.39	1.68	1.87	2.01	1.85	1.93	max. elongation 208.4 mm
Reference (Best off)	2.23	1.86	2.23	-	-	-	-	-	max. elongation 19.6 mm

Mechanical Properties of 21411 Belts

Load-displacement diagram of tensile tests on 21411 Belt

➢ Load-Displacement curve



Tensile test results:

- ➢ Similar load at break (strength) for both.
- ➢ Higher stiffness for Phoenix.
- ➢ Higher elongation at break for Reference Belt

Conclusions:

- ➢ Phoenix Belt achieves **similar load at break** with the Reference Belt but exhibits **higher stiffness**.
- ➢ In this case, the **Reference Belt**'s lower stiffness, higher elongation at break and higher energy absorbed before failure indicate overall **better mechanical behavior**.

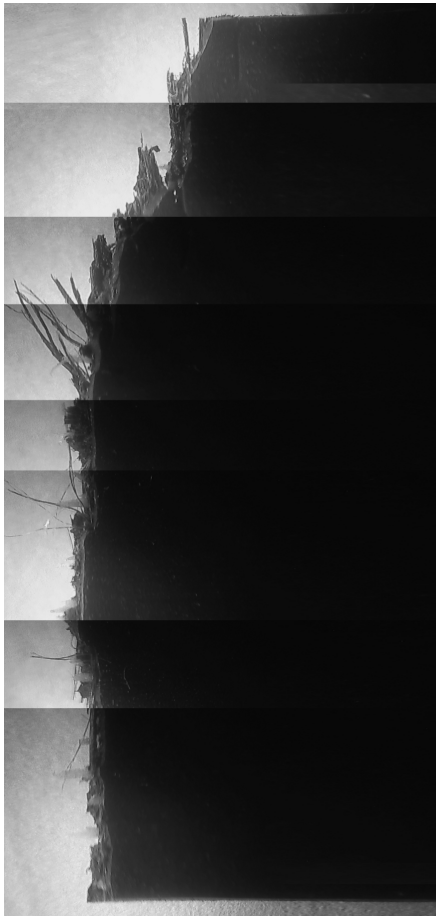
Note: Statistical accuracy is not given due to low number of test specimens

Table: Results of tensile tests on Phoenix belt and Reference belt according to DIN 53504

spec. no.	Maximum Load (KN)	Load at 10 mm (KN)	Load at 20 mm (KN)	Load at 25 mm (KN)	Load at 30 mm (KN)	Load at 35 mm (KN)	Load at 40 mm (KN)	Load at 45 mm (KN)	Remarks
Phoenix A	1.86	0.67	1.19	1.42	1.64	1.83	-	-	max. elongation 35.9 mm
Phoenix B	1.77	0.62	1.12	1.35	1.57	1.75	-	-	max. elongation 35.4 mm
Reference B	1.88	0.55	0.99	1.18	1.37	1.55	1.72	1.87	max. elongation 45.4 mm
Reference A	1.82	0.50	0		1.30	1.48	1.64	1.79	max. elongation 48.1 mm

Optical Examination on fractures of 21411 Belts

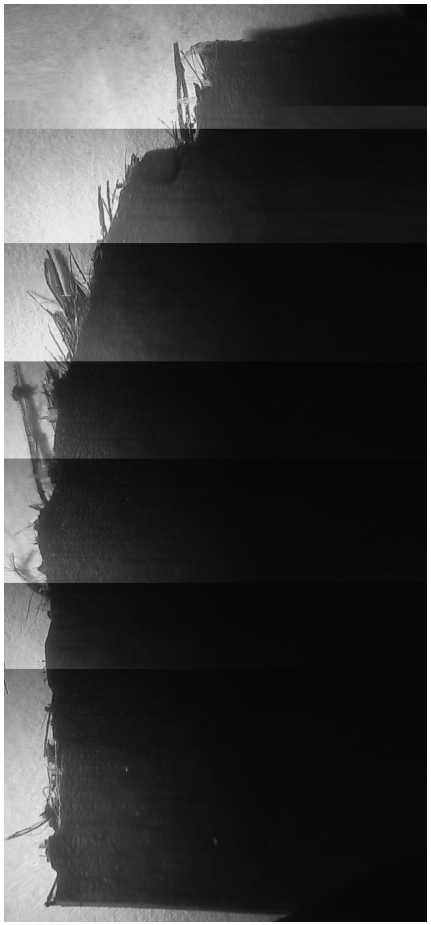
Phoenix Belt



Optical examination results:

- The fracture surface of the reference belt appears relatively more compact and less rough (with no visible signs of layer debonding within the composite matrix) compared to the Phoenix belt, suggesting a more abrupt final failure for the genuine belt.
- The Phoenix belt exhibits a more pronounced fibrous and irregular fracture surface, with longer fiber pull-out lengths and clearly visible reinforcement bundles. This indicates that, prior to final failure, a greater degree of fiber debonding and pull-out from the matrix occurred, which is associated with a more progressive failure mechanism and increased energy absorption during loading.

Reference Belt



Summary and Conclusions

- Differences between Phoenix and Reference components are small in steel and composite components, and highly in favor of Phoenix in polymer components.
- Phoenix steel components have comparable material properties to the Reference components, but Phoenix could improve their components significantly by additional surface heat treatment at critical positions (e.g. bearing seats).
- The dimensional accuracy of steel components is in general comparable on all critical positions.
- The mechanical properties of the Phoenix O-rings were superior to their Reference counterparts.
- Reference Rectangular Ring 13394, and possibly O-ring 21416, were defective with both exhibiting highly inferior mechanical properties compared to their Phoenix counterparts.
- The mechanical properties of the composite components were better for the Reference components.
- Further optical examination demonstrated better fracture behavior for Phoenix belt.
- All measurements in this study were made on new polymer, composite and steel components from Phoenix and on new Reference components. Therefore, statistical evidence of the results is not possible. If customers would return damages parts, failure analysis could lead to better understanding of specific application-oriented problems of the component designed and manufacturing.