Influence of Silicon Carbide Structure on Running Capabilities of Hard-Hard Pairings in Marginally Lubricated Conditions

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Introduction

Over many years, hard/soft pairings have been applied successfully as dynamic seal rings in sliding seals and as bearings in pumps. Carbon graphite materials are used as soft partners. Increasingly hard/hard pairings of silicon carbide materials are being applied. Presently, a wide range of material variations of sintered silicon carbides (SSiC) as well as reaction bonded silicon carbides (RbSiC) are available.
These traditional silicon carbide materials show excellent wear resistance in fully lubricated applications, even those containing abrasive particles, however, some means of improved performance is required in marginally lubricated applications, which can result in silicon carbide chipping, cracking and even catastropic failure. In this work, pairings of traditional and other silicon carbide structures have been subjected to severe test conditions. Test results have demonstrated that the proper pair selection of silicon carbide structures can help resolve problems dealing with marginally lubricated conditions.

Materials

During the past few years, SiC materials have improved substantially. Variation of the materials‘ structure as well as graphite additives are means to improve their running capabilities under marginal lubrication. At the same time research in carbon graphite materials is yielding improvements in strength and wear resistance-. These improvements, combined with improved silicon carbide counterfaces, promote further tribological improvements.

Figure 1 shows a list of some hard materials used in friction pairings.

Figure 1 **Popular hard materials in tribological applications**

Type of Material	Material	Characteristics
Metall Carbides	Tungsten Carbide	Wear resistant sintered material (binder: Co, Ni, CrNiMo)
Silicon Carbides	SSiC, RbSiC	Sintered or reaction bonded silicon carbides
Metal Oxides	Aluminum Oxide	Sintered metal oxide (normally high purity)
Metals	Steel	Predominantly hardened steels

This work is concerned with silicon carbide materials.

The behaviour of materials in tribological applications (as i. e. silicon carbides) cannot be related totally to their physical properties. The strongest material is not necessarily the best material for all tribological applications.

Figure 2 shows a selection of silicon carbide materials which would allow a good variation for the purpose of this work.

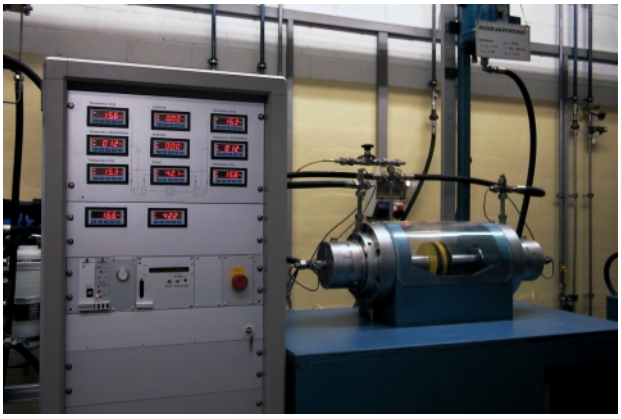
Figure 2 **Tested materials**

Material	CarSIK	SD	ST	ST*G	NT	FT	CT	SiC 30
Type of Material		SSiC	SSiC (porous)	SSiC-G (20vol.%G)	SiSiC (coarse)	(fine)	SiSiC-G 15vol.%G	SiC/G-compos. mat. 43vol.%G
	Unit							
Hardness Vickers		2500	2500	2300	2500	2500	*	*
Raw Density	g/cm_	3.10	3.05	2.8	3.09	3.09	2.90	2.65
Compressive Strength	MPa	3800	2500	1500	3000	3000	650	600
Bending Strength	MPa	390	280	200	280	300	120	140
Modulus of Elasticity	*10_MPa	400	370	250	360	360	260	140
Coefficient of Thermal Expansion	$*10^{-6}$/K	4.0	3.9	4	3.9	3.9	4.0	3.0
Thermal Conductivity	W/mK	110	100	110	175	175	130	125
Temperature Resistance	K	1993	1993	1993	1653	1653	1653	2400
Temperature Resistance in Air	K	1993	1993	1993	1653	1653	873	873

* Depends if point of test is on SiC or graphite.

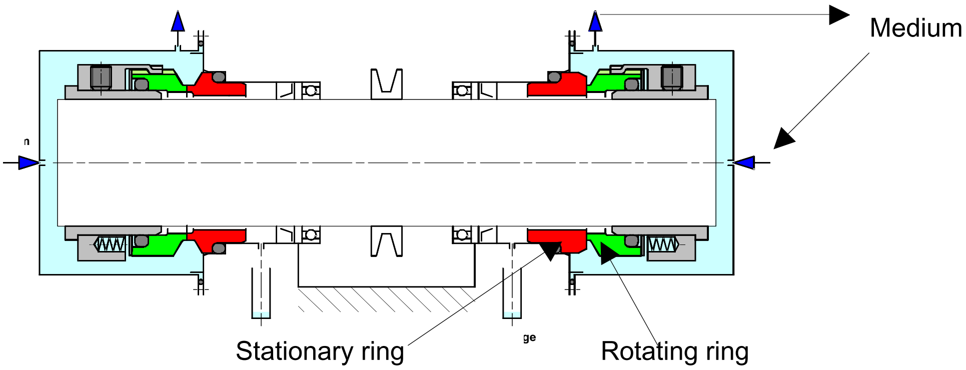
Test facilities

The tests were performed with a mechanical seal, high pressure test rig, at the below application conditions. Pict*ure 1* shows the test rig which is operated with two seals. These seals are equipped with hard/hard or hard/soft pairings.



Sliding speed: 9.35 m/s
Balance ratio: 0.79
Liquid: Deionized Water
Temperature: 20 — 90 ¡C
Pressure: 0.5 — 10 MPa
(5 — 100 bar)
Shaft diameter: 50 mm

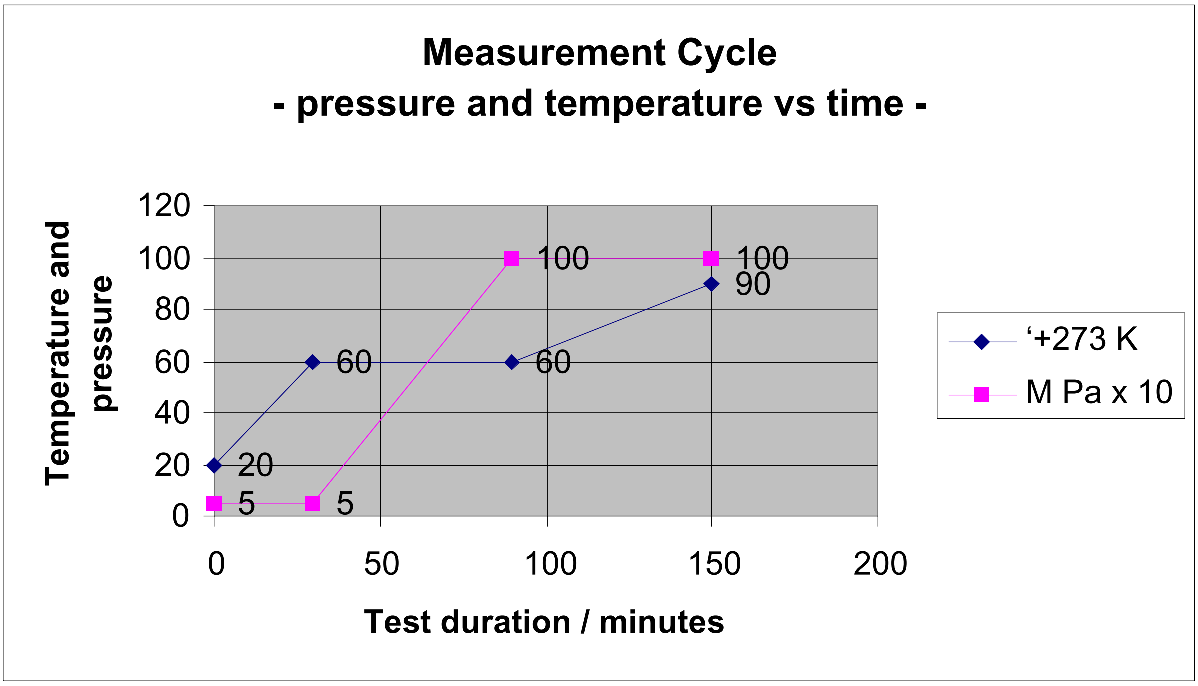
Picture 1: Mechanical Seal High Pressure Test Rig



Test procedure

Sliding speed = 9.35 m/s; pressures up to 13 MPa are possible. Deionized water, which may be heated, is used as the media. Computer controlled cycles with modified pressure and temperature are monitored with respect to pressure, temperature and power consumption. The power consumption correlates with the frictional values of the pairing. The experimental set-up and the measurement cycles allow testing of carbon graphite materials in hard/soft pairings as well as the materials in hard/hard pairings to controlled overload. In short time, comparison measurements of the tribological properties at marginal lubrication can be determined. Marginal lubrication is achieved by increasing both pressure and temperature during the test. This leads to a reduced film thickness and the pressure in the gap falling below the vapour pressure of water. A breakdown of hydrodynamics and marginal lubrication result in power consumption spikes.
Figure 3 shows the measurement cycle.

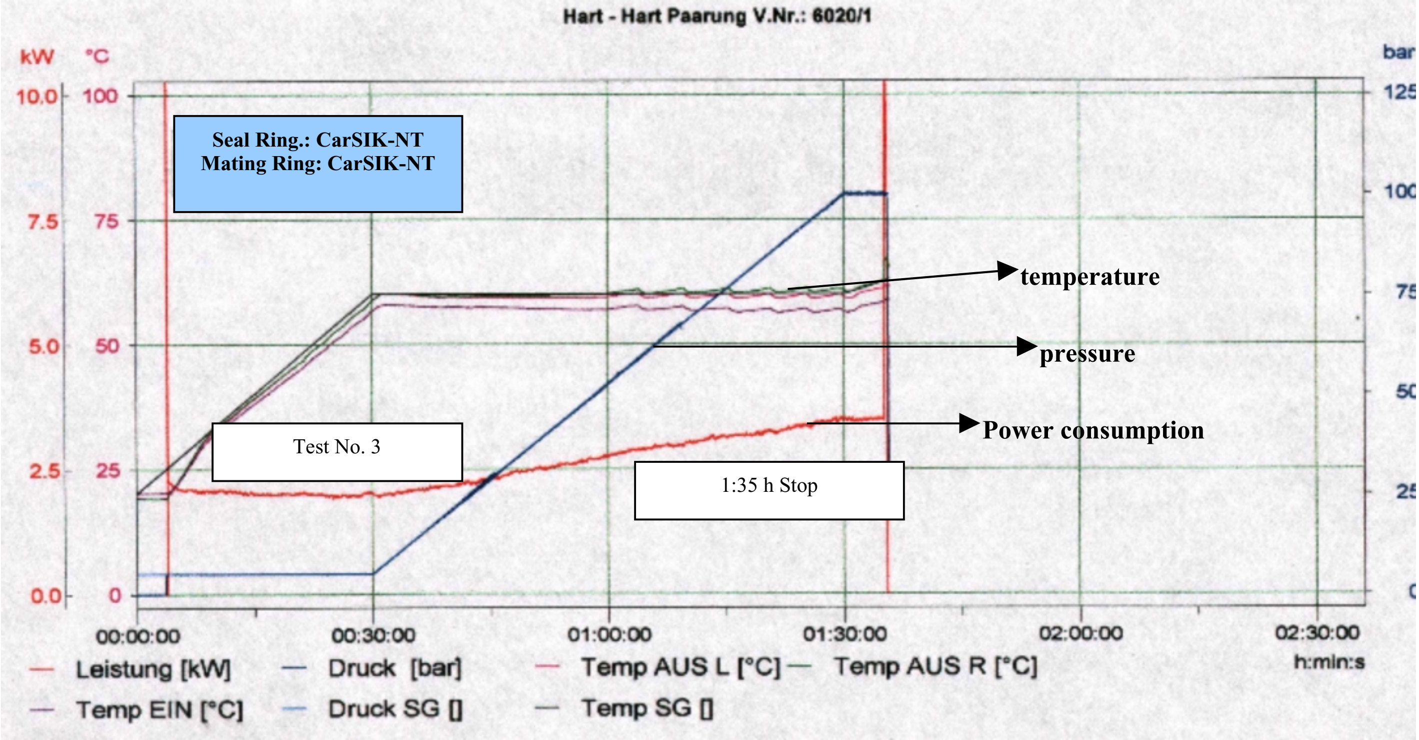
Figure 3	**Measurement cycle**

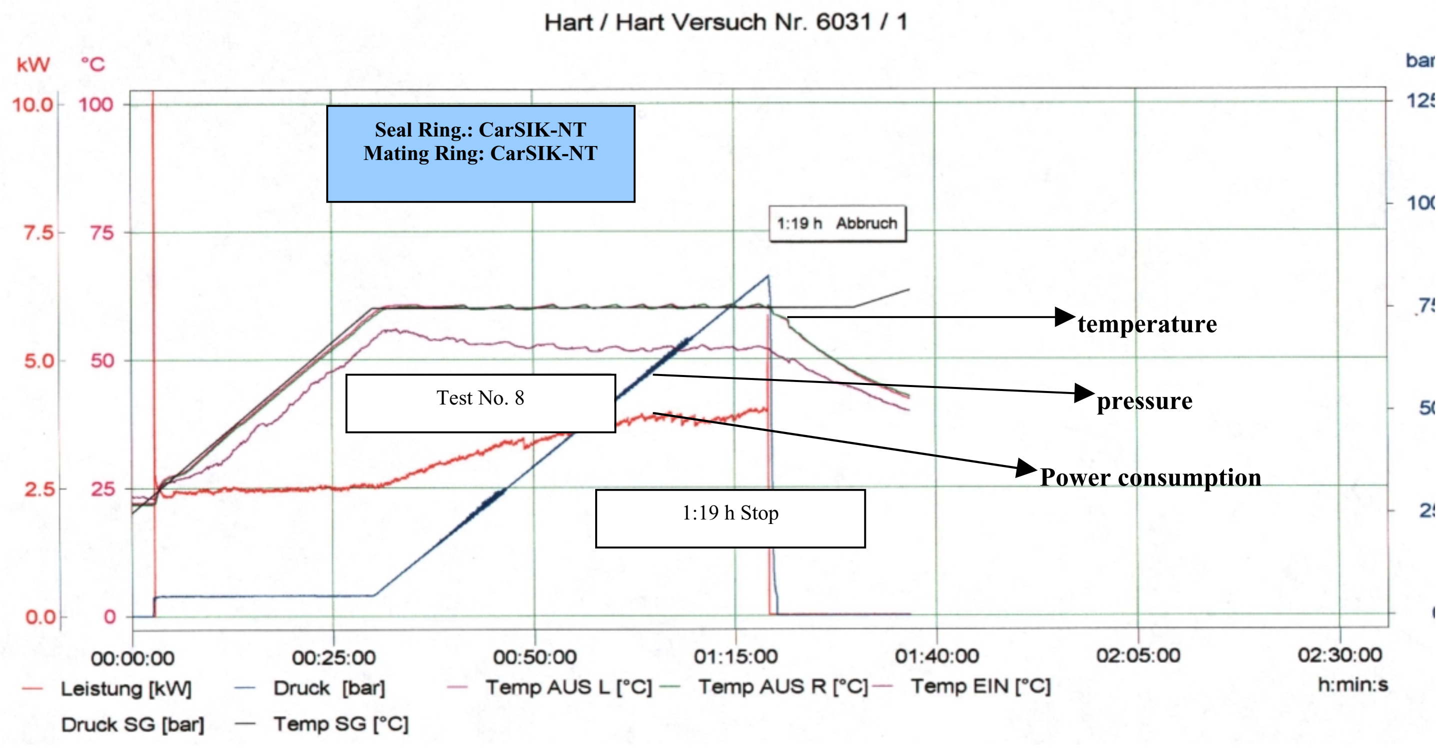


The test starts with a media temperature of 293 K at 0.5 MPa media pressure. Within 30 minutes, the temperature rises to 333 K, within further 60 minutes the pressure rises from 0.5 bar to 10 MPa ultimate pressure. Subsequently, the temperature increases to 363 K in maximum within 60 minutes.
The test is completed when power consumption spikes occur. Pairings with better running characteristics have longer run times without power spikes within the standard test cycle. Therefore, the time of the test, along with the achieved pressure and temperature, is a measurement of the tribological quality of the investigated pairing.

The reproducibility of the results was verified by using the pairing CarSIK-NT against CarSIK-NT. *Figure 4* shows the reproducibility of the measurements. The corresponding results generally are sufficient within reasonable limits, thus suggesting the suitability of the testing facility and the testing parameters for the measurement of marginal lubrication levels for specific material pairs.

Figure 4 **Reproducibility**

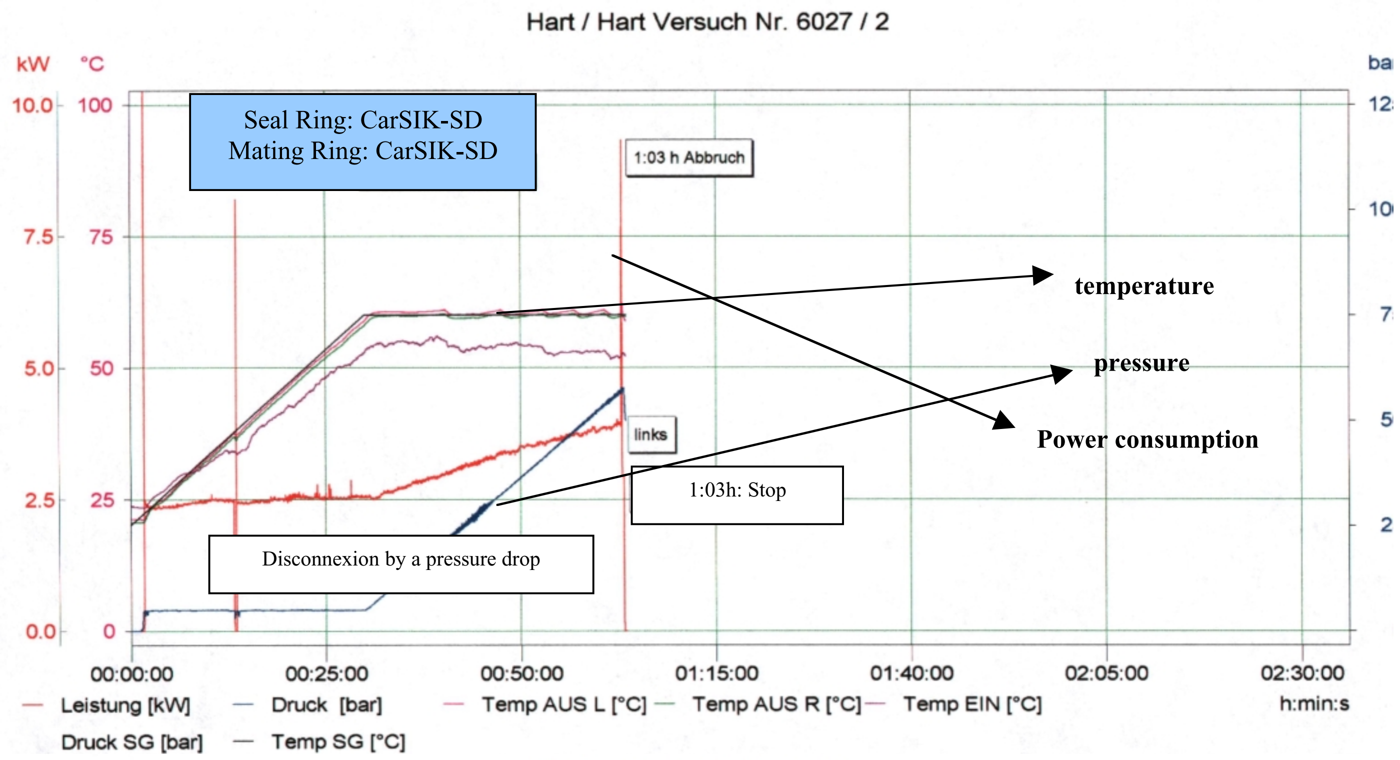




Results

The *figures 5* to *7* show the comparison of the behaviour of one suitable and one non-suitable hard/hard pairing as well as of one hard /soft pairing.

Figure 5:	**-Lowest results**	Figure 6 :	**-Best results**



Seal Ring: CarSIK-SD
Mating Ring: CarSIK-SD

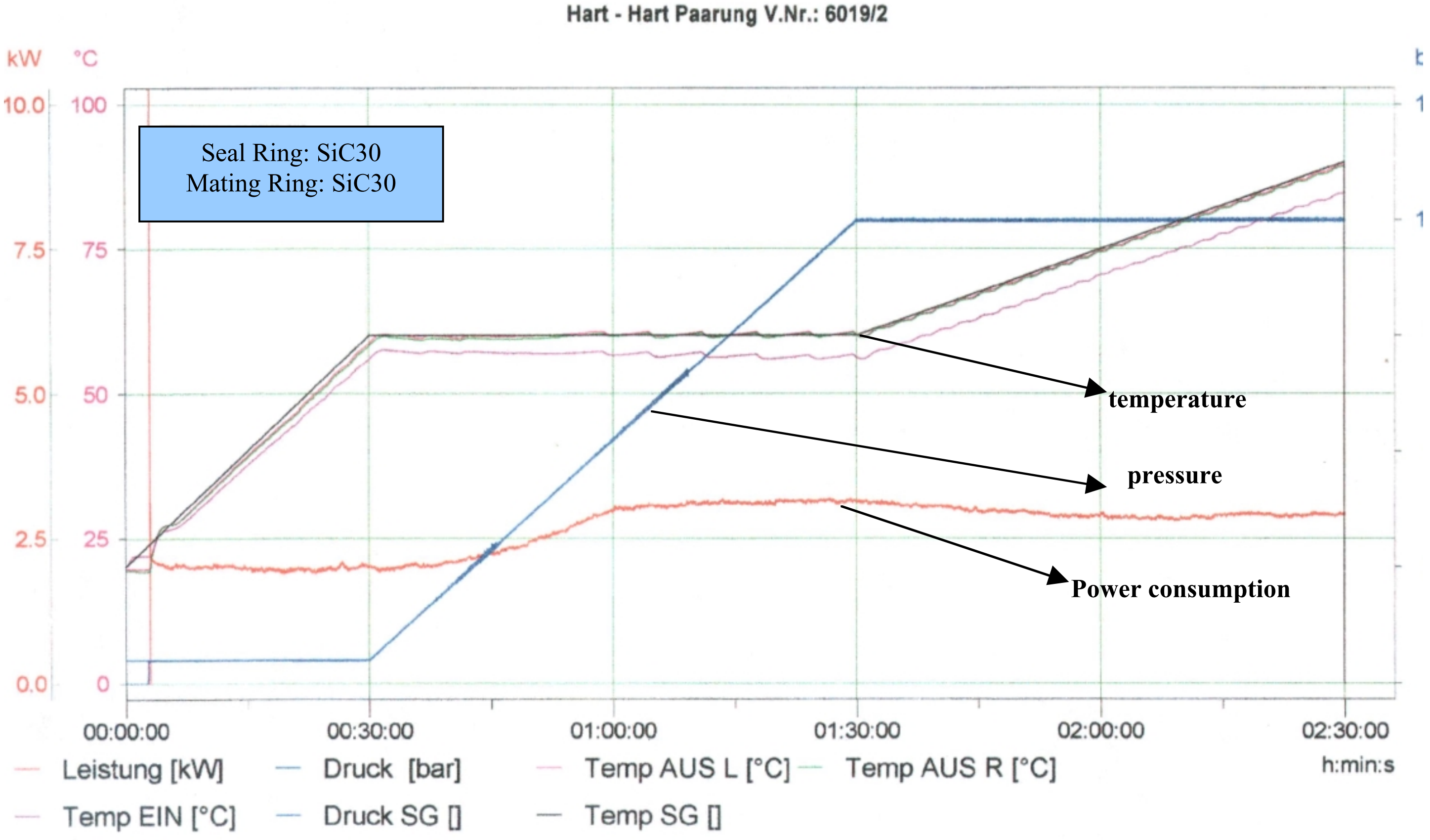
temperature

pressure

Power consumption

1:03h: Stop

Disconnexion by a pressure drop



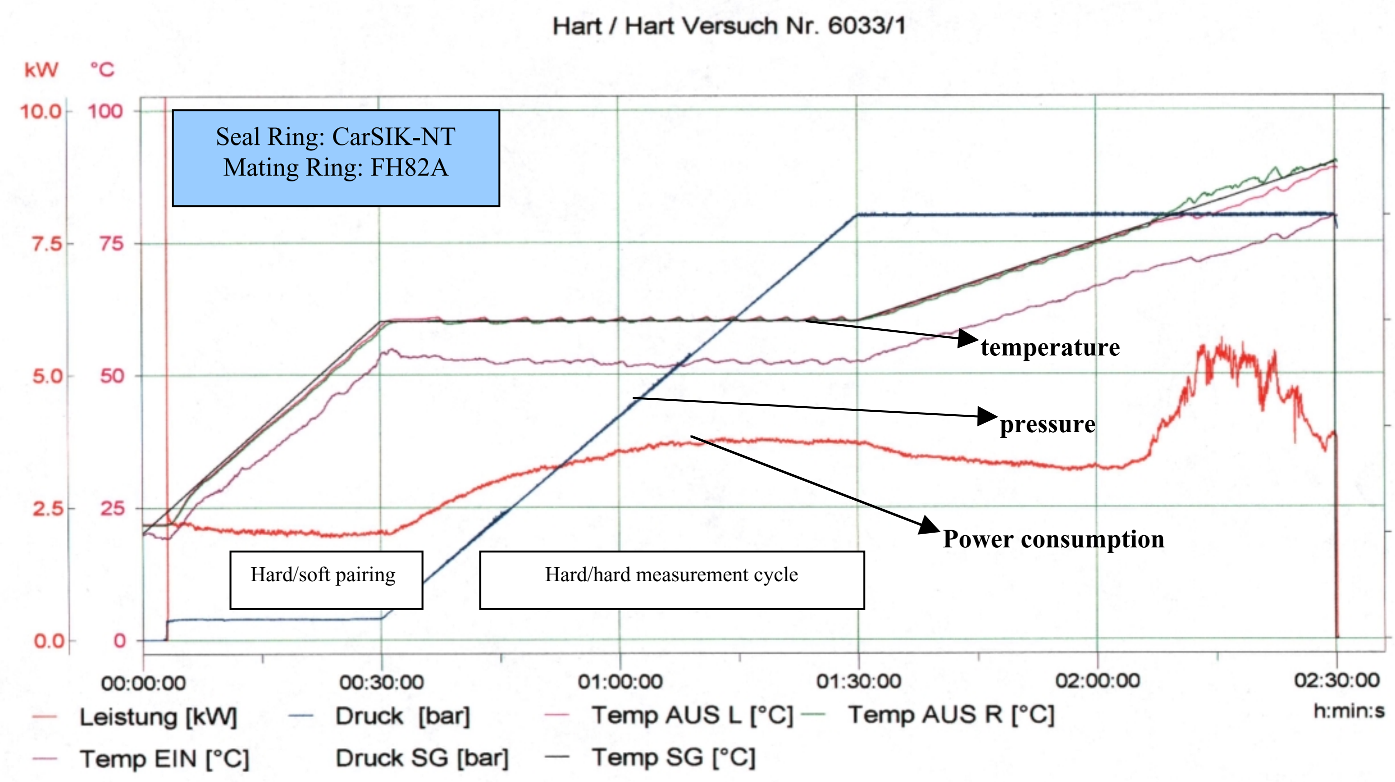
Seal Ring: SiC30
Mating Ring: SiC30

temperature

pressure

Power consumption

Figure 7: **Comparison of a hard/soft pairing**



While the test CarSIK-SD against CarSIK-SD *(figure 5)* had to be stopped after 63 minutes due to power spikes, the test SiC30 vs SiC30 (figure *6)* reached the longest test time without power spikes. The limit of the pair was not reached.

The testing procedure not only helps to achieve reasonably reproducible results but is also well-suited for investigating the running capability under marginally lubricated conditions. *figure 7* shows the curves of a hard/soft pairing with dry-running properties. As an example an antimony impregnated carbon (FH82A) was tested against CarSIK-NT.

Why is the running behaviour of similar materials so different?
There are characteristic differences in the texture of the materials. *Picture 2* shows some materials« textures which are important for the interpretation of the test results.

Carbon graphite consists of different fillers embedded in a carbon matrix. The main constituent is carbon/graphite, which exhibits dry-running properties. Carbon graphite is applied as the soft partner in a hard/soft pairing with dry-running capabilities.

SSiC mostly shows a very fine-grained texture with small closed pores; the SiC content is higher than 98,5 %.

RbSIC (coarse texture) consists of primary and secondary SiC (SiC content : > 87 %); the content of free silicon amounts to approximately 12 %.

RbSiC-C consists of primary and secondary SiC containing about 15 vol.% larger graphite grains.

The SiC-C composite material, SiC30 (shown at the bottom of the picture), consists of a matrix of SiC and graphite. The high graphite content of about 43 % by volume (35 % by weight) together with a few remaining free silicon areas is unique.

Other tested materials with different microstructures are not shown here for space purposes. They are: SSiC (with discrete holes), RbSiC (fine texture) and SSiC-G (with graphite content).

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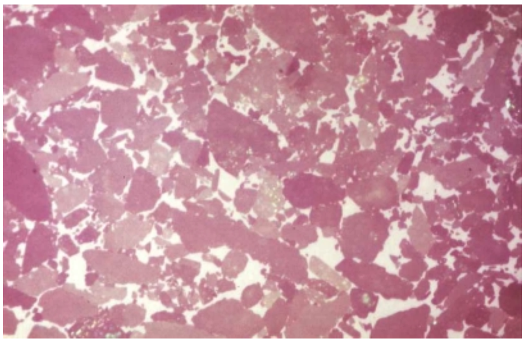

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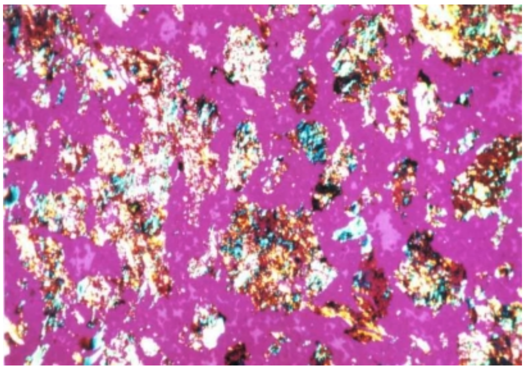

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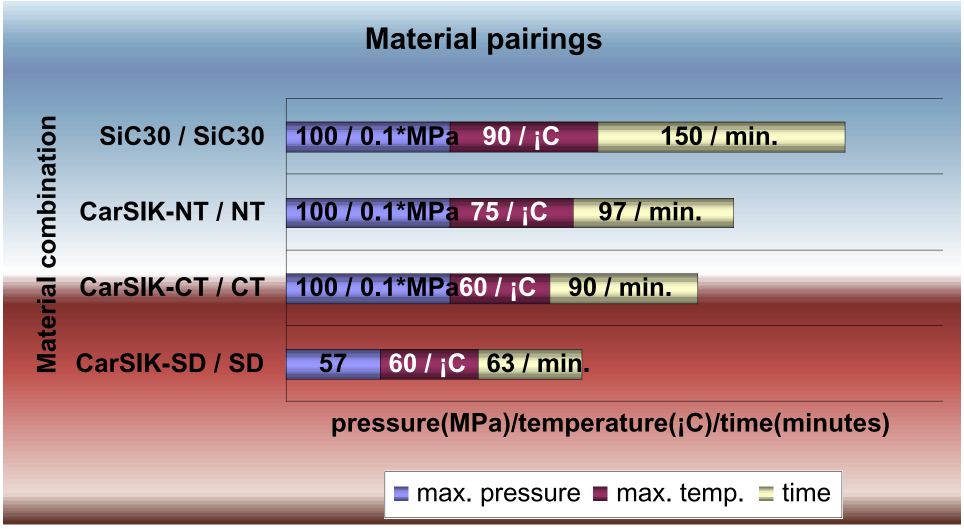
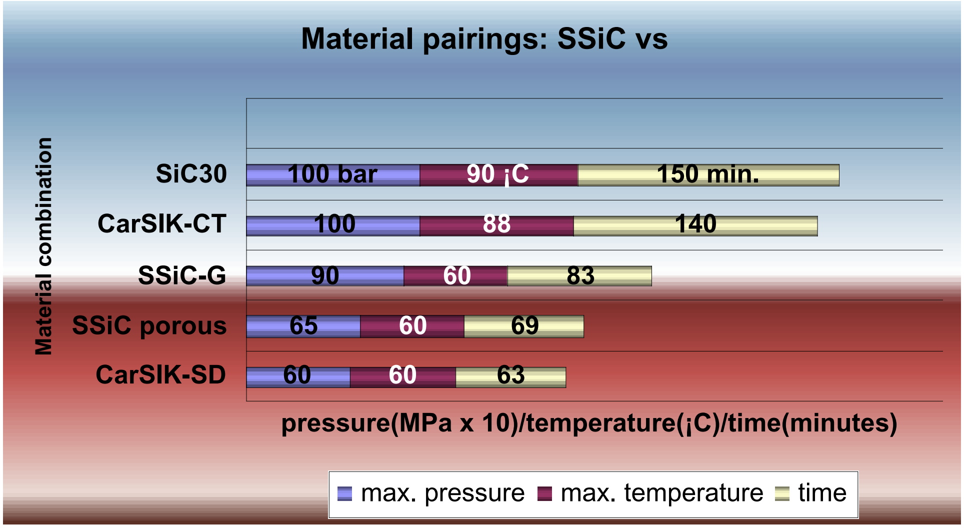
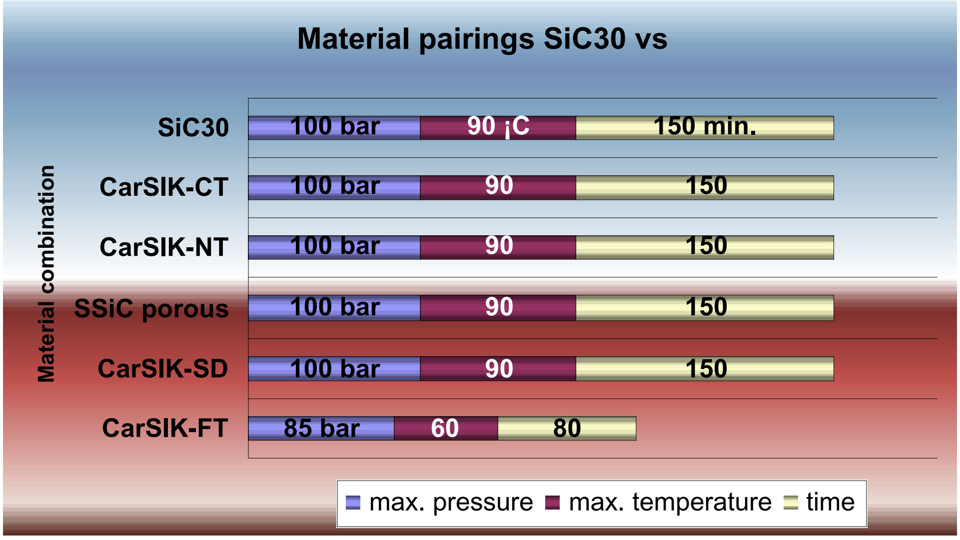
The *figures 8* to *10* show comparison measurements of different material pairings. In *figure 8*, pairings of identical grades are described. The behaviour of coarse-grained RbSiC materials (CarSIK-NT) is superior to that of fine-grained SSiC (CarSIK-SD). The SiC-G composite material (SiC30) is best, even at highest loads.

Figure 9 shows the behaviour of different materials, each paired with SSiC (CarSIK-SD). The SSiC variant with modified textures (-ST ªporous and -ST*C ª carbon containing) show a significantly improved behaviour under marginally lubricated conditions. Again, the best results are achieved with coarse materials which consist of different phases (graphite), such as RbSiC-G (CarSIK-CT) and the SiC-G composite material, SiC30.

Figure 10 shows the significant effect of the mating material. The special structure of the SiC-G composite material, SiC30, gives superior tribological properties in almost every material combination.







Conclusion and outlook

The described testing procedure is an excellent tool for measuring the tribological properties of hard/hard pairings under marginally lubricated conditions. These pairings differ significantly and cannot solely be explained by physical properties of the materials. Their microstructures have a strong influence.

The data collected in this report point out that some SiC pairs are able to perform better than others as marginal lubrication occurs. The marginal lubrication level therefore, is different for different SiC pairs. Higher graphite contents and more complex, and perhaps coarser, microstructures have higher marginal lubrication levels.

The SiC-G composit material SiC30, having 43 vol.-% graphite — the highest graphite content tested — and a complex microstructure gave the best results when run against itself and most other SiC materials. While SSiC (sintered SiC), having a dense, fine grained porosity structure, gave lower results — running against itself and other SiC materials — except versus SiC30.

In this work the SiC30 vs most other SiC materials gave comparable results to a soft-hard pair (carbon graphite material versus a reaction bonded SiC material like CarSIK-NT).

A large variety of materials is already available.

The developement of further interesting materials with outstanding properties will help overcome the edge between "hard and "soft sliding pairings. Hard/hard pairings and hard/soft pairings will increasingly enter new application fields.