

TRIBOLOGICAL PROPERTIES OF CARBON AND GRAPHITE IN DRY ATMOSPHERE

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Abstract

Since decades graphite is known as a self lubricating material. This valuable behaviour is used in many applications. Additional positive properties of graphite like chemical durability and neutrality leads for uses as additive in lubrication oils and greases. The use of graphite for lubrication applications and additional functions in pure shape is common known for dynamic and static seals, vanes for dry running compressors and vacuum machines and bearings.

Nevertheless graphite can loose its self lubrication property in particular conditions. Early noted was this behaviour in graphite brushes for planes. The dry conditions in high altitude lead to abrasive wear. Additives has to be used to avoid this problem. Well known is the problem for seals and bearings used in dry nitrogen atmosphere which is a common requirement in the chemical industry.

Although the lost of the self lubricating property is a contemporary issue it is hard to find information about thresholds for application requirements. For industrial use it would be helpful to know the correlation between humidity and start of abrasive wear. Older information speak about 3g/m^3 absolute humidity when abrasive wear starts. For a better understanding of abrasive wear in typical industrial applications examinations were done on a test rig for dry running vanes. With respect to different materials, velocities, gases and humidity the start of abrasive wear was examined.

Introduction

A well known application for graphite material is the use of vanes in compressors to apply pressure or vacuum. The principle of operation is based on the so called "rotary vane compressor" to generate pressure or vacuum.

The environmental conditions in which the compressors are used can be very different. Typical conditions are from room temperature with different humidities according to the geographic locations to outside conditions with temperatures below 0°C .

From experience it is well known that the humidity have a big impact on the wear of these vanes. In a vacuum environment and at low temperatures there is a lack of humidity for good self lubricating properties. Both conditions have the same result: There is an increasing wear of the vanes.

To simulate such conditions a test rig was developed which is able to run in vacuum and pressure. This test rig was adapted at the principle of a real compressor. Test on this test rig were conducted with different groups of materials as they were used in real applications. Common materials are resin bonded graphite and artificial graphite impregnated with salt. Additional tested were resin impregnated carbon graphite and graphite material. The test conditions vary in the velocity, pressure and type of gas.

Experimental

1. Materials

Materials which were tested on the test rig are allocated to the following material groups:

A. Resin bonded graphite filled vanes

B. Carbon graphite, impregnated with phenolic resin

C. Artificial graphite

D. Artificial graphite, impregnated with different resins

E. Artificial graphite, impregnated with different salts

Most materials are available on the market. In some cases new impregnation agents were used to check their potential for improvement in dry running conditions.

The main differences between resin bonded and pitch bonded materials are their physical properties and their manufacturing times. Both types are used in the same applications.

To simulate low humidity vacuum, nitrogen and argon the tow latter with different content of water were used. Nitrogen 5.0, 5.3 and 5.6 with a water content below 5ppm, 2ppm and 1ppm and Argon 5.0, 5.3 and 5.6 with a water content below 3ppm, 2ppm and 1ppm were available for the test runs.

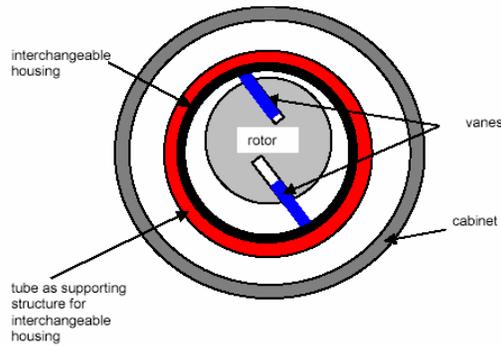
2. Sample preparation

Because of the availability on the market the samples were taken out of the common production or were purchased. In case of new impregnation agents the impregnation procedures were partly conducted in lab scale and production facility. Common production parameters regarding vacuum/pressure operation were used.

3. Test rig

The concept of the test rig is adapted from conventional compressors. It is not possible and not the target of the test rig to generate pressure or vacuum for use. Furthermore it was the target to

apply vacuum and a certain atmosphere out of pressurized air, nitrogen or argon. The concept of the test rig is shown in picture 1.



Picture 1: Concept of test rig.

The possible settings regarding velocity are between 5 and 20m/s. The contact pressure of the vanes was adjusted with their weight. Further possibilities for adjustments are the media, the temperature, the angle of the vanes in the rotor, the number of vanes and the material mating.

The results which were collected from the tests are the coefficient of friction, the development of temperature and the wear of the vanes.

4. Test program

The vane samples were characterized by means of weight and dimensions. After installation in the test rig the interchangeable housing was rinsed with the test gas for 10minutes. In case of pressure the test pressure was adjusted. In case of vacuum the housing was rinsed at 200mbar absolute pressure with the test gas for 10minutes. Then the vacuum was adjusted. The results shown in this paper are results which were conducted at 12m/s for 60minutes. After the test run the vane samples were characterized again by means of weight and dimensions. Within this paper only the wear results are reported. The interchangeable housing was in all examinations cast iron (GG25).

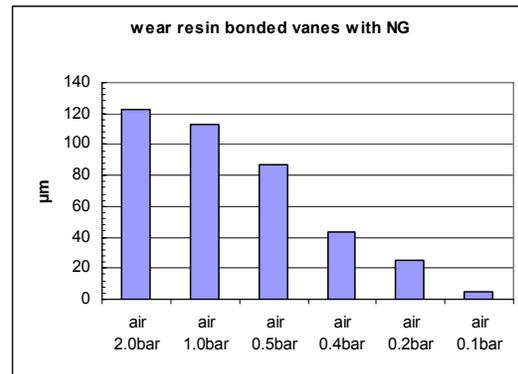
Results and discussion

Resin bonded graphite

Resin bonded graphite vanes were tested in air, in nitrogen and in argon. The pressure in air was varied from 0.1bar up to 2bar and tests were conducted in nitrogen 5.0, 5.3 and 5.6 with 1bar and in argon 5.0 with 1bar and 2bar. Altogether two different type of resin bonded graphite vanes were tested. One sample is based on natural graphite and the other sample is based on artificial graphite.

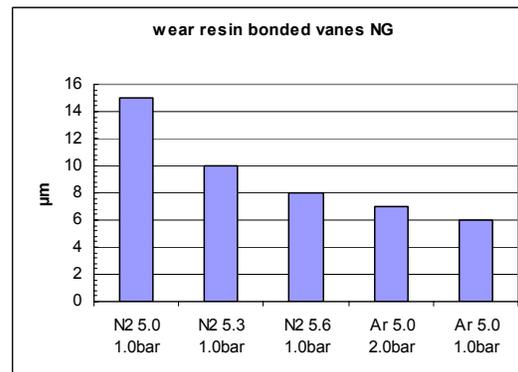
Picture 2 shows the results of resin bonded natural graphite in air at different pressures. It is clearly to see that the wear after the test is decreasing with decreasing pressure. Although the humidity is decreasing with decreasing pressure

there was no indication for rapid wear. In contrast the wear is significantly reduced presumably due to the less work with decreasing pressure.



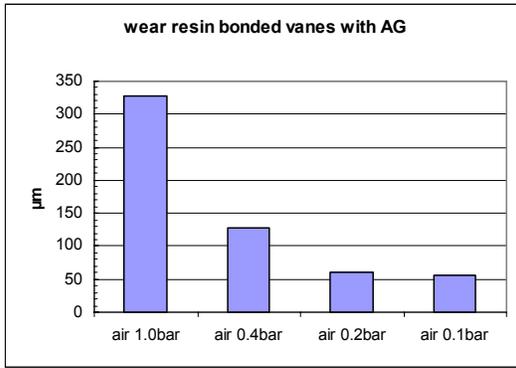
Picture 2: Wear of resin bonded natural graphite vanes.

Tests of resin bonded natural graphite vanes in nitrogen and argon showing a comparable result. This is given in picture 3. With decreasing humidity the wear is decreasing too. The results are indicating that the minimum wear is around 8µm. Comparing the results in nitrogen and argon with the results in air the wear in 0.1bar air is comparable with the wear in nitrogen 5.6.



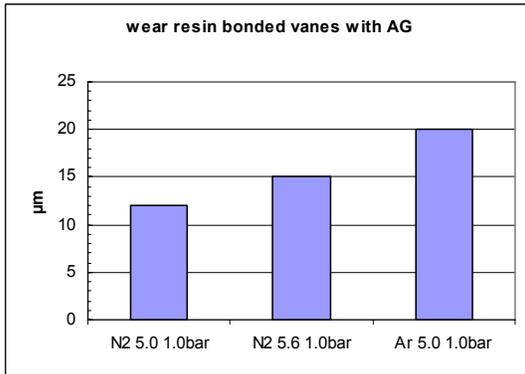
Picture 3: Wear of resin bonded natural graphite vanes.

Test results of resin bonded artificial graphite vanes showing in general comparable behavior. Picture 4 shows the wear of resin bonded artificial graphite vanes in air at different pressures. With decreasing pressure the wear is decreasing too. But in comparison to natural graphite the absolute wear is higher with artificial graphite.



Picture 4: Wear of resin bonded artificial graphite vanes.

With decreasing humidity in nitrogen it seemed to be that resin bonded artificial graphite vanes have an increase in wear. This could be derived from picture 5 where the wear of resin bonded artificial graphite vanes in nitrogen with different humidity and in argon is shown.

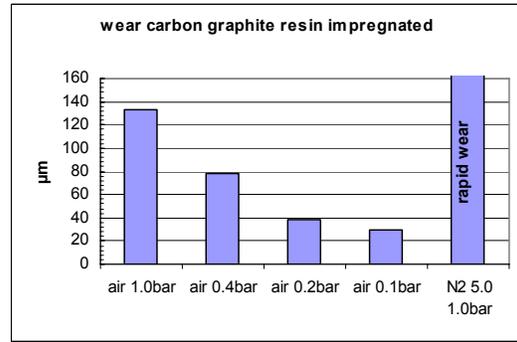


Picture 5: Wear of resin bonded artificial graphite vanes.

Carbon graphite impregnated with phenolic resin

Carbon graphite vanes impregnated with phenolic resin were tested in air at different pressures from 0.1bar up to 1bar and in nitrogen 5.0 at 1bar. The wear of these vanes is shown in picture 6.

The wear in air is in some degree comparable with the wear of resin bonded natural graphite vanes as showed in picture 2. The wear is decreasing with decreasing pressure. But in contrary to the wear results of resin bonded natural graphite vanes the carbon graphite vanes impregnated with phenolic resin have rapid wear in nitrogen after some seconds.



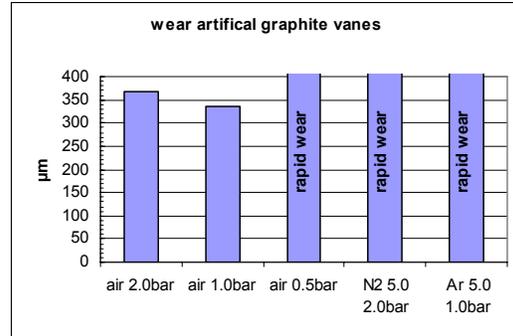
Picture 6: Wear of carbon graphite impregnated vanes.

Artificial graphite

Artificial graphite vanes were tested in air from 0.5bar up to 2bar and additional in nitrogen 5.0 and in argon 5.0. In nitrogen the pressure was 2bar and in argon the pressure was 1bar.

The wear of artificial graphite in air is quiet high compared for example with resin bonded artificial graphite. It decreases with decreasing pressure but with an air pressure of 0.5bar the vanes show rapid wear after some seconds.

As expected from this results the artificial graphite vanes exhibit a rapid wear behavior in nitrogen and argon after a very short time of some seconds.



Picture 7: Wear of artificial graphite vanes.

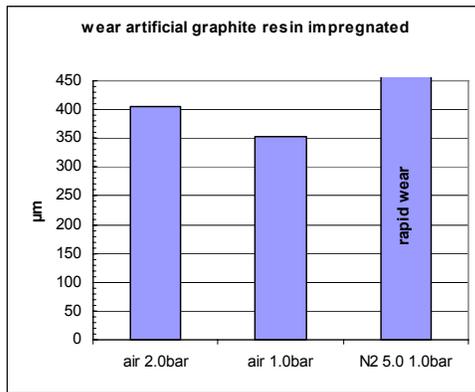
Artificial graphite impregnated with resins

Artificial graphite vanes impregnated with two different resins were tested in air and nitrogen 5.0. The pressure in air was varied from 0.1bar up to 2bar. The pressure in nitrogen 5.0 was 1bar.

Picture 8 shows the wear result of artificial graphite vanes impregnated with phenolic resin and picture 9 shows the wear of artificial graphite impregnated with a new development resin suitable for higher temperature durability.

The wear of artificial graphite impregnated with phenolic resin in air is at that level of artificial graphite without impregnation. At least it is somewhat higher. In nitrogen the artificial graphite

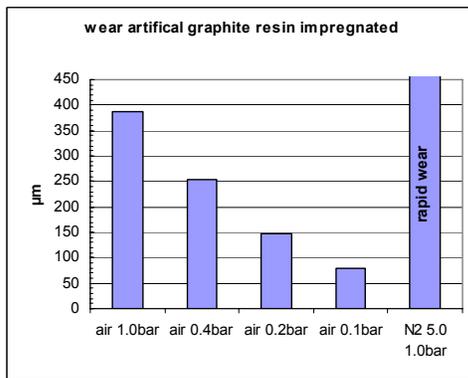
vanes impregnated with phenolic resin show rapid wear after short time of test.



Picture 8: Wear of artificial graphite resin impregnated vanes.

The wear of the artificial graphite vanes impregnated with a new development resin for higher temperature durability offers the same development of decreasing wear with decreasing pressure. Fortunately it was possible to reach a pressure of 0.1bar in air without rapid wear behavior.

Nevertheless in case of using nitrogen as test gas the wear behavior of artificial graphite vanes impregnated with the development resin is that of rapid wear. In dry atmosphere there was no improvement regarding declining the wear with this kind of resin.



Picture 9: Wear of artificial graphite resin impregnated vanes (development resin).

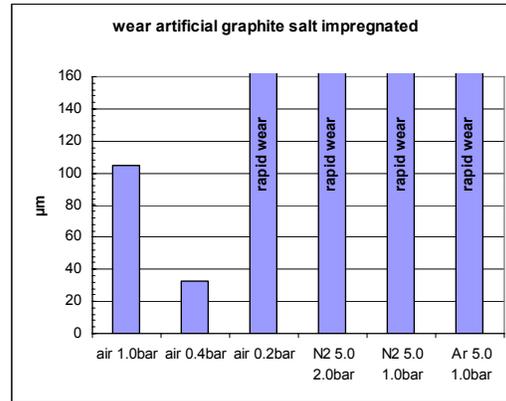
Artificial graphite impregnated with salts

Artificial graphite vanes impregnated with salts were tested in air, nitrogen 5.0 and argon 5.0. The pressure in air was varied from 0.1bar up to 1bar. The pressure in nitrogen was 1bar and 2bar. Two different types of artificial graphite were used.

The wear of one type of artificial graphite impregnated with salt is showed in picture 10. In air the wear was decreasing with decreasing pressure. At 0.2bar rapid wear occurs. With the salt impregnation it is possible to decrease the wear of

artificial graphite significantly if ones comparing the wear in picture 7 and in picture 10. But the minimum pressure is at least between 0.4bar and 0.2bar.

Using the artificial graphite vanes impregnated with salt in dry atmosphere as given by the usage of nitrogen or argon rapid wear occurs after some seconds of test time.

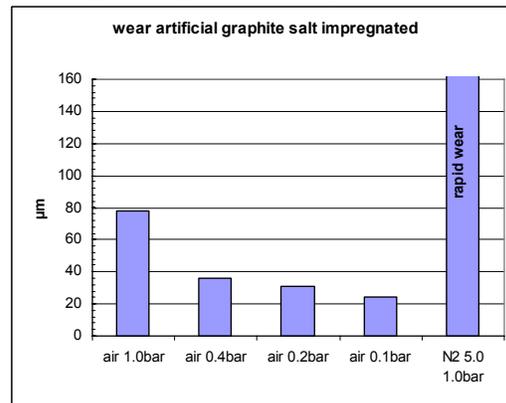


Picture 10: Wear of artificial graphite salt impregnated vanes.

Taking another base material of artificial graphite the wear behavior is different. The wear of artificial graphite based on another base material impregnated with salt is showed in picture 11.

The wear level starts at a slightly lower level and is decreasing with decreasing pressure. Additionally it is possible with this base material to reach lower pressures than with the base material used for the results which are showed in picture 10.

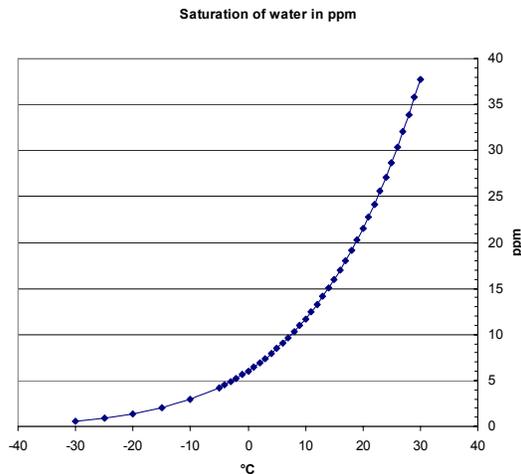
Nevertheless it was not possible to run artificial graphite vanes impregnated with salts in nitrogen. After some seconds of test time rapid wear was occurring in nitrogen 5.0 with a pressure of 1bar.



Picture 11: Wear of artificial graphite salt impregnated vanes.

Conclusion

The requirements regarding wear in dry atmosphere in vane type compressors are based on the application in low temperature and/or vacuum. In both cases the humidity which is necessary for the self lubrication behavior of carbon and graphite is very low. It was a target of these tests to approach to the boarder line of humidity content which is necessary to avoid rapid wear. It was assumed from experience that the threshold of humidity is around 3ppm. This will lead to the suggestion that at least below temperatures of -6°C carbon and graphite loses its self lubricating properties as it could be taken out from picture 12. It shows the dependency of 100% humidity content and temperature. Unfortunately it was not possible with the used test gases to consider a wider range of humidity than between 1ppm an 5ppm.



Picture 12: Absolute humidity (100%) in dependence on temperature.

With the tests in different atmospheres and at different pressures it could be shown that the most suitable material combination for vanes are made out of resin bonded natural graphite. They have the lowest amount of wear and are suitable for application in extreme dry atmosphere too. Unfortunately the application temperature is limited according to the temperature durability of the resin. In these cases where temperature is an issue the choice is artificial graphite vanes impregnated with salts. Important for the level of wear is the base grade of artificial graphite.