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**TRIBOLOGICAL PROPERTIES OF SILICON INFILTRATED SiC GRADES CONTAINING CARBON PARTICLES**

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**Résumé** - Le matériau SiSiC est intéressant pour de nombreuses applications telles que les roulements, bagues d'étanchéité ou pièces de pompes du fait de ses excellentes propriétés tribologiques. Cependant le comportement du matériau n'est pas satisfaisant dans des conditions de fonctionnement purement à sec. Un matériau SiSiC modifié avec différents teneurs en particules de carbone a été développé, il combine la grande résistance à l'usure du SiSiC et le faible coefficient de frottement du carbone. Le comportement tribologique de ces matériaux ainsi que les mécanismes d'usure ont été étudiés.

**Abstract** - SiSiC-ceramic is useful for many applications ie bearings, seal rings or pump parts because of its excellent tribological properties. Exceptionally under purely dry running conditions the material's behaviour is unsatisfying. Modified SiSiC with different content of carbon particles was developed which combine the high wear resistance of SiSiC and the low friction coefficient of carbon. For these materials the tribological behaviour and the wear mechanism was investigated.

**I - INTRODUCTION**

SiSiC <sup>(1)</sup> has a combination of excellent thermomechanical and chemical properties and is also remarkable for its high degree of shape retentivity and dimensional stability during production and service.

Its extreme hardness and favourable wear resistance are especially useful for applications such as seal rings, bearings, protective sleeves for shafts, sliding rails and guide rollers, as well as engine components such as rocker segments, valve guides and pushrods.

The main stress is that of sliding friction, combined with high erosive, thermal or chemical attack.

Hitherto, the tribological behaviour of brittle, ceramic materials was determined unsystematically /1, 2/. This behaviour is simply a property of the system as such and is influenced by numerous parameters, i.e. the nature of the stress, such as sliding friction or rolling friction, the materials combination, the surface conditions and the lubricant /3/. In cases of pure fluid friction and also with mixed friction the lubricant is very important. Under dry running conditions the main factor is the materials combination. Some

(<sup>1</sup>) SiSiC (reaction-bonded silicon-infiltrated silicon carbide)

measurements on several material combinations - involving SiSiC together with metallic or ceramic materials - have shown that SiSiC gives low friction coefficients and displays very low wear in cases of fluid friction and mixed friction, whereas it fails under dry running conditions, which are more severe /1/.

The object of this work was to modify the SiSiC material in composition and microstructure in such a way as to achieve low friction coefficients and low wear even under purely dry running conditions.

## II - EXPERIMENTALS

To improve the tribological properties of SiSiC, the composition of the material and also its microstructure have been modified.

Carbon and graphite materials, when subjected to sliding friction, form a lubricating film which exerts a beneficial effect on the friction coefficient and wear behaviour. Therefore we tried to combine the properties of SiSiC and those of carbon materials. Carbon-containing SiSiC grades were manufactured and measurements were made, both the sliding properties and the wear. The wear mechanism was investigated with a scanning electron microscope (SEM).

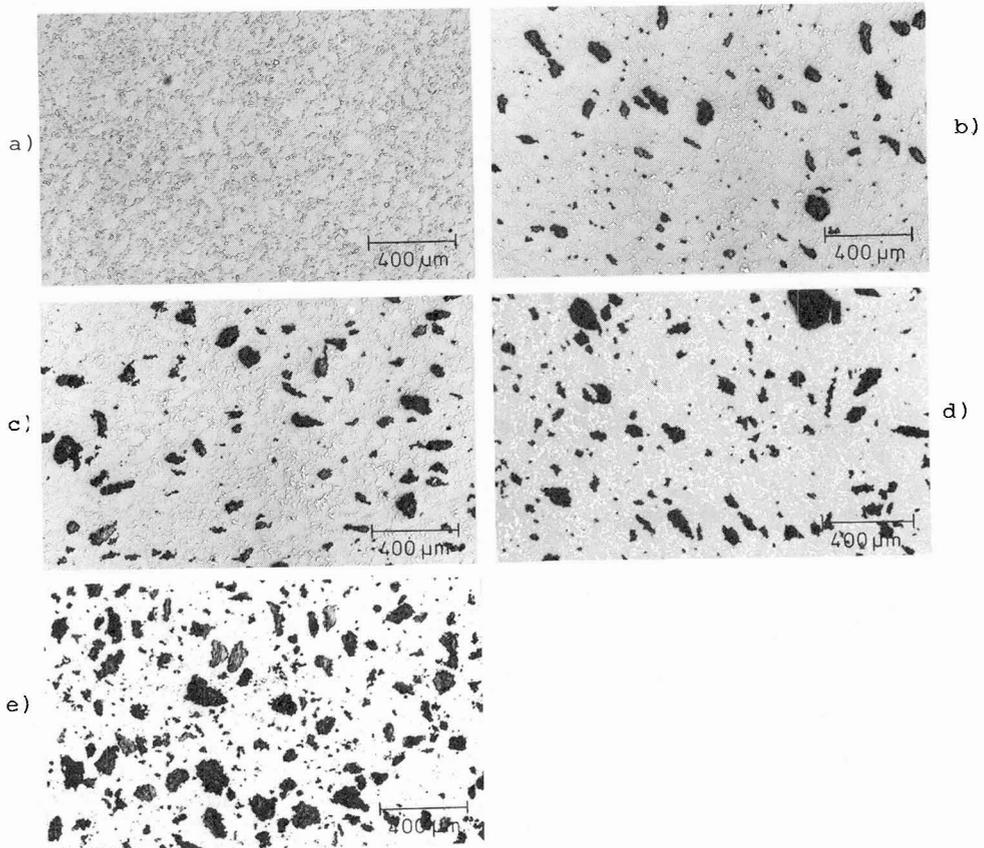


Fig. 1: The structure of carbon-containing SiSiC (photomicrographs)  
a) 0 % C    b) 1 % C    c) 2.5 % C    d) 5.5 % C    e) 10.5 % C

In the normally used fabrication process /4/ the carbon is converted completely in order to produce optimum material properties, but in the production of carbon-containing SiSiC some unreacted carbon needs to be retained. The main factor governing the reaction with silicon is the nature of the carbon /5/. Other important factors are particle shape and size of the carbon. The carbon particles must exceed a critical size if they are not to be fully transformed into SiC. Elongated particles are siliconized more easily than spherical particles. Other influencing factors are the reaction temperature, reaction time and atmosphere.

With due regard to the various influencing parameters, SiSiC materials were manufactured with carbon contents of 1, 2.5, 5.5, and 10.5 %.

Fig. 1 shows the microstructure of these samples in comparison with carbonfree SiSiC. The wear behaviour and friction coefficient of the materials were measured as functions of the sliding way (Bundesanstalt für Materialprüfung, Berlin). The technique employed was a pin-on-disc method. The carbon-containing SiSiC material was used as the disc; and SiSiC without carbon, tungsten carbide with 6 % cobalt, and carbon (Ringsdorff-Werke, Bad Godesberg) were used for the pin.

$$k = \frac{W_L}{F_N s}$$

$W_L$  = wear rate of the disc  
 $F_N$  = normal force  
 $s$  = sliding way

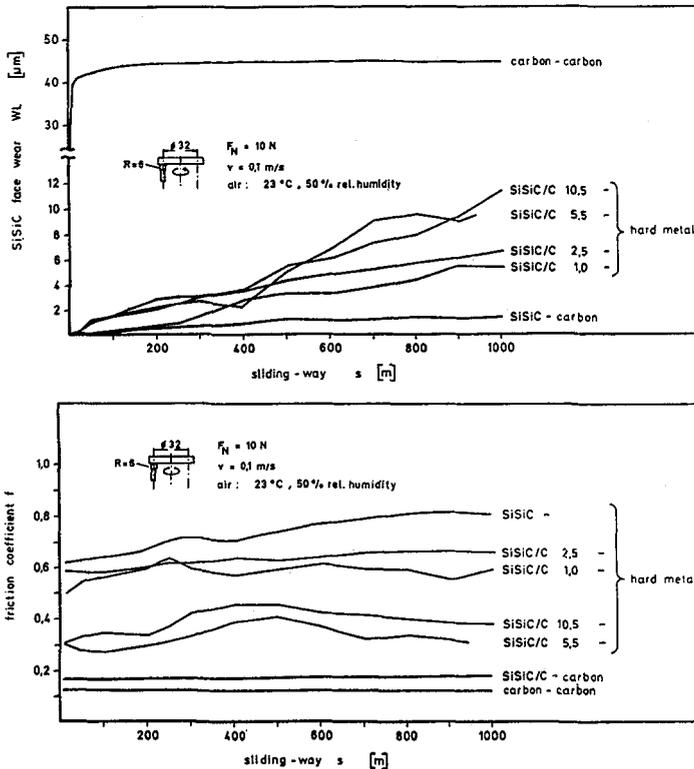


Fig. 2: Wear  $w_L$  and friction coefficient  $f$  of several material combinations as functions of the sliding distance

The results obtained under dry running conditions are illustrated in Fig. 2. The values plotted are for the linear wear factor  $W_L$  and the friction coefficient  $f$  as functions of the sliding way. Scanning electron micrographs of surface of the test specimens are shown in Fig. 3.

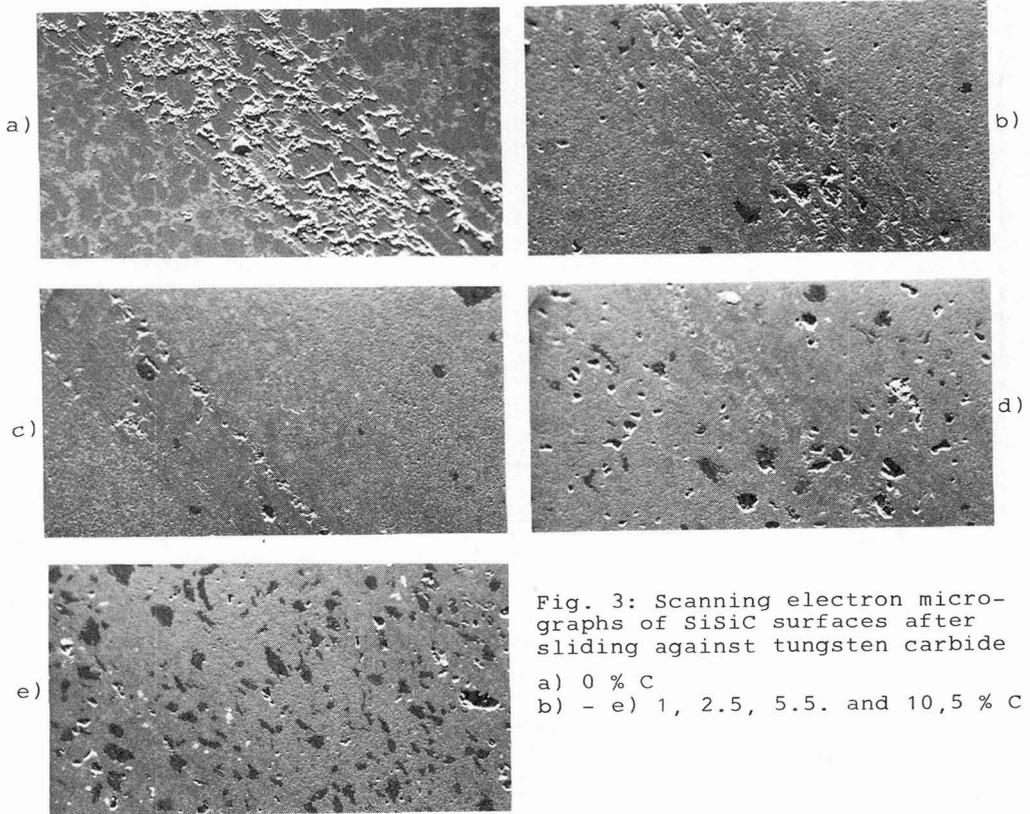


Fig. 3: Scanning electron micrographs of SiSiC surfaces after sliding against tungsten carbide

a) 0 % C  
b) - e) 1, 2.5, 5.5. and 10,5 % C

### III - RESULTS

According to Fig. 2, the materials combinations used in the sliding tests can be arranged in the following order:

1. The SiSiC/tungsten carbide pairs has the highest friction coefficient of 0.62. In addition, the friction coefficient increases with the sliding distance: this suggests a certain tendency towards scoring.
2. Among the carbon-containing SiSiC materials the friction coefficient declines with an increase in added carbon. At up to 5.5 % added carbon the effect is only slight, and above 5.5 % carbon the friction coefficient is only  $f = 0.3$ . The scatter of the friction coefficient as a function of the sliding distance decreases with an increase in the proportion of carbon. It ceases to rise, and there is no longer any tendency towards scoring.

3. The comparative materials combinations of SiSiC/carbon and carbon/carbon have even lower friction coefficients, namely  $f = 0.17$  and  $f = 0.13$  respectively.
4. The differences in the rate of wear are only slight. There is a slight tendency to greater wear with an increase in the proportion of carbon.

Wear during the running-in varies greatly. This is due to the random distribution of the carbon in the material's structure. Fig. 1 shows that the number of carbon particles involved in the sliding process are greater if the amount of added carbon is higher and that its distribution becomes more uniform. This has a direct effect on the reproducibility of the measured values.

These interpretations are confirmed by photographs of the material grades used in the wear tests: Fig. 3. The photographs show that the degree of roughening, ie surface indentation, in the region of the sliding interface, declines with an increase in the amount of carbon added.

The friction coefficient of carbon-containing SiSiC modifications under dry friction is very low in comparison with other materials /1, 2/.

The SiSiC/carbon combination gives reason to expect that, with an even higher proportion of carbon, it will be possible to reduce the friction coefficient still further and achieve values below 0.2. The theoretical aspects underlying the development have such been confirmed.

#### IV - LITERATURE

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