4th International Conference
"Industrial ENGINEERING - INNOVATION AS COMPETITIVE EDGE FOR SME"
29 - 30th April 2004, Tallinn, Estonia

CHROMIUM CARBIDE BASED CERMETS AS THE WEAR RESISTANT MATERIALS

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Abstract: *Cr_3C_2 based cermets are developed to achieve unique combination of properties that could not be found in component materials. This cermet has low melting point, medium fracture toughness, high hardness, and good oxidation resistance. The major advantages of chromium carbide based cermets are their low price and possibility to use at high temperatures. In the presented paper the mechanical properties, abrasion and erosion resistances of chromium carbide based cermets are studied.*

For high temperature application, the thermal properties such as coefficient of thermal expansion, thermal conductivity coefficient, and thermal shock resistance are important. These parameters have a great effect on lifetime of the ready-made details and are presented and discussed in this study.

Keywords: *Wear resistance; Mechanical properties; Chromium carbide based cermet; Thermal properties*

1. INTRODUCTION

Combination of such important properties as high hardness, good strength, medium fracture toughness and excellent oxidation resistance results nowadays in growing interest to Cr_3C_2 based cermets. The controlled modification of hard particle-binder composition, properties (particle size, alloying etc.) and production technology gives opportunities for applications in different industrial areas that involve tribo-corrosion processes (Wang & Shui, 2002; Hoop & Allen, 1999; Eroglu & Duran, 1997; Tkachenko et al., 1978; Uusitalo et al., 2002; Li & Ding, 2000; Toma et al., 2001; Mateos et al. 2001; J.Föhl et al., 1989).

Present work was done to summarize and evaluate the effect of wear process variables on material lost rate for different chromium carbide based cermet compositions. Sufficient work has been done in this direction in Tallinn Technical University (Pirso, 1996; Hussainova, 2001a, b). Weight percentage of carbide grains varies between 60 and 100%. The effect of impact velocity, impact angle and temperature was evaluated with use of high temperature abrasive erosion tester described in details elsewhere (Hussainova, 2003). Impact velocity and angle varies in between 10÷80m/s and 30÷90º, respectively. Temperature range investigated was 20÷600ºC. Obtained data is presented in form of maps that enable to choose optimal composition of ceramic-metal material for specific work conditions. The advantage of presenting of numerical data in form of maps for other materials has been already shown by Stack et al., 1997.

The use of composite materials at high temperature conditions is restricted by the internal stresses caused by different thermal properties of components. Additional impact is done by corrosion-oxidation processes. To evaluate the effect of specimen size, shape and composition of Cr_3C_2 based cermets on temperature changes, thermal shock experiments were hold. The use of more suitable shape of detail leads to increase in lifetime and therefore have an effect on the efficiency of material application.

2. EFFECT OF MICROSTRUCTURE ON MECHANICAL PROPERTIES

Mechanical properties of chromium carbide based cermets are strongly dependant on microstructure. The main variables that influence the material composition and properties are:

- ✓ Binder content (Ni)
- ✓ Size of carbide grains (Cr_3C_2)
- ✓ Porosity

In general, an increase in tough Ni binder content results in increase in fracture toughness and transverse rupture strength and decrease in hardness (Fig. 1).

The effect of composition and average carbide grain size on compressive strength is shown in Fig. 2. As it can be seen cermets with high carbide content exhibit brittle mechanism of fracture under compressive strength. Only material with 50 wt% deforms plastically and shows 3% deformation before fracture.

In mechanical testing, carbide grains carry most of the load due to mismatch of Young's modulus. Ni has the possibility to deform plastically. Tests have shown that the highest stresses are concentrated in largest grains. It was found that transverse rupture strength of Cr_3C_2 based cermets has almost linear inverse logarithmical dependence on average size of five largest grains (Pirso, 1996).

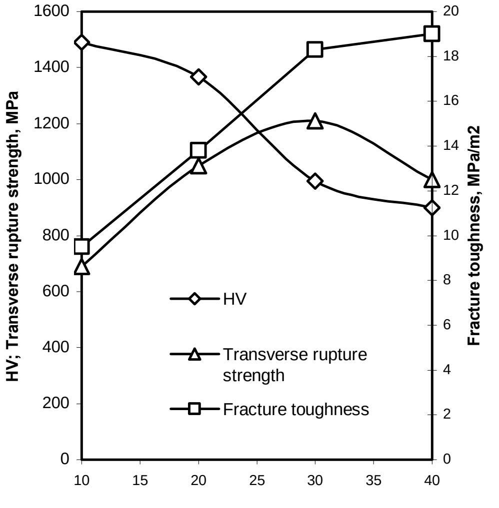

Figure 1. Effect of Ni binder content on mechanical properties of chromium carbide cermets.

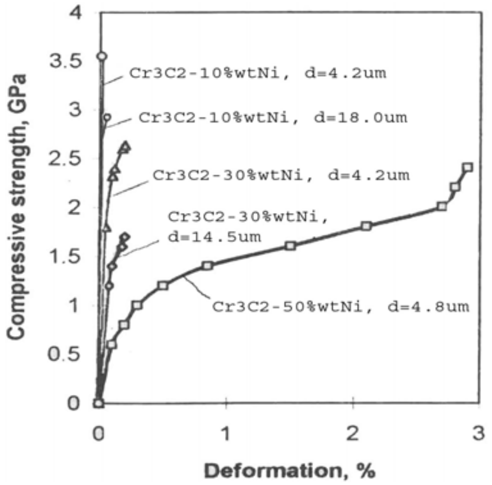

Figure 2. The effect of composition and average carbide size on compressive strength (Pirso, 1996)

Effect of porosity on mechanical properties could be described as the presence of stress concentrators or as voids that increase the speed of crack nucleation.

3. EFFECT OF MICROSTRUCTURE ON OXIDATION AND CORROSION RESISTANCE

Study of corrosion and oxidation resistance of chromium carbide based bulk materials and coatings has shown that they have excellent resistance to oxide compared to other cermets and hard metals (Pirso, 1996; Uusitalo et al., 2002; Wang & Shui, 2002). 850ºC is found as the most appropriate maximum temperature for application of these materials in wear conditions.

Figure 3 shows oxidation dynamics of Cr_3C_2 with different binder content. At temperature of 800ºC oxidation rate is low enough. WC-Co hard metals degrade completely at this temperature.

The most intensive weight gain due to oxidation can be seen at first 50 hours and then have the tendency to slow down. An increase in temperature from 800ºC up to 900ºC results in increase of weight gain up to 10 times. It was also found that further increase of temperature up to 1050ºC results in the similar increase in weight gain up to 10 times. Binder content has evident effect on oxidation resistance only at temperature lower than 800ºC.

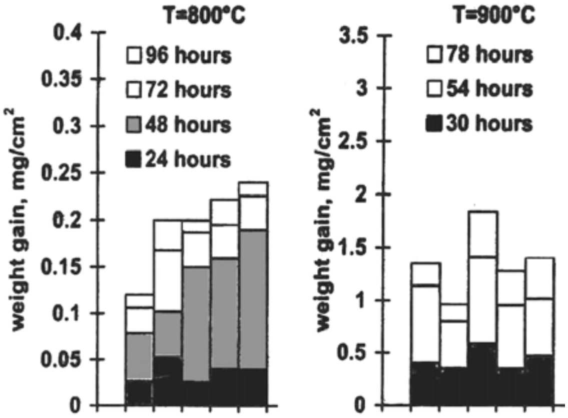

Figure 3. Oxidation of Cr_3C_2-Ni cermets, depending on binder content, temperature and testing time. Oxidation environment-air. (Pirso, 1996a)

4. EFFECT OF MATERIAL COMPOSITION AND TEST CONDITIONS ON WEAR RATE.

The mechanism of material removal during erosion is strongly dependent on material composition and test conditions. Impact of abrasive particles during erosion results in surface layer formation with properties that differ from bulk material. Change of properties of the surface layer depends on prevailing mechanism and possibility of the layer to react with abrasive dust and splitters. Thus the hardness of cermet with high tough binder content could be increased by captured abrasive dust which results in their higher erosion resistance at impact angles near normal (at low impact angles abrasive particles do not have enough kinetic energy to hammer dust into cermet).

The most important test condition variables are:

- ✓ Impact velocity
- ✓ Impact angle
- ✓ Temperature
- ✓ Properties of abrasive (size, hardness)

Velocity and mass of an abrasive particle determine its energy. Particles that have higher energy can produce greater damage in a surface. The erosion rate has a power dependence on the velocity of impact. This dependence is not valid for materials with a high level of porosity. These materials have a threshold after that the erosion rate increases dramatically (Hussainova, 2001b).

While impact velocity mostly influences the dynamics of erosion, the impact angle directly affects the mechanism. Thus at high impact angles, low-cyclic friction fracture mechanism is prevailing and such properties as fracture toughness and fatigue characteristics are important. In the case of oblique angles the dominating mechanism is microcutting and ploughing and hence hardness value is important. That is why more brittle composites with low binder content have the highest erosion rate at high angle (75÷90º) of impact and grades with lower hardness have the maximum erosion rate at oblique angles (20÷50º). To achieve good erosion resistance, the cermet should have equal or higher hardness than an abrasive. The angles of maximum erosion rate as a function of composition, impact velocity and temperature are listed in Table 1.

At high temperature, the angles of maximum erosion rate are shifted 5 – 10^0 to a lower value. Especially affected material is the grade with Ni content of 10 wt%. Temperature increase makes its behavior more ductile and it shows a better erosion resistance at normal impact angles as compared with resistance at oblique angles.

Figures 4 and 5 show the effect of binder content, velocity and temperature for oblique and normal impact angles. Erosion rate below 1 mm^3/kg is taken as low, 1÷10 mm^3/kg is taken as medium and erosion rate above 10 mm^3/kg is taken as high erosion rate.

		Composition and temperature (20ºC* and 600ºC)**			
		10%wt Ni	20%wt Ni	30%wt Ni	40%wt Ni
Impact velocity/s	20	75÷90* 60÷75**	90* 75÷90**	75* 75**	75* 75**
	60	75* 60÷75**	90* 75÷90**	75* 75**	60÷75* 60**
	80	75* 60**	60÷75* 75**	75* 75**	60÷75* 60**

Table 1. Maximum erosion rate angles as a function of composition, velocity and temperature. Abrasive - silica particles with diameter of 0.2÷0.6 mm. Carbide particle size 3.0÷9.0µm. Porosity – about 1 %.

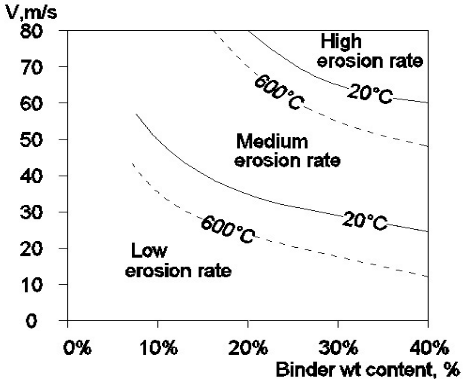

Figure 4. Erosion rate map. Impact angle is 30º. Abrasive-silica with diameter of 0.2÷0.6 mm. Carbide particle size 3.0÷9.0μm. Porosity – about 1%.

It can be seen that increase in velocity and binder content leads to increase in erosion rate. Erosion rate of cermets with Ni content of 40 wt% at 25 m/s is of the same value as for cermets with 10 wt% of Ni binder content at 55m/s. Starting from 300°C temperature increase the erosion rate evenly for all compositions. Increase in temperature up to 580ºC has almost the same influence as increase in velocity up to 15 m/s.

Figure 5 shows that at the normal angle of attack cermets have got a higher erosion rate as compared to that at the oblique angle of attack. In the case of low velocities (up to 20m /s) and normal angle of impact, binder content has almost no influence on the erosion rate if Ni content exceeds 10 wt%.

At high impact angle, the erosion rate of cermets is more velocity affected and composites exhibit a high erosion rate just at 40 m/s in the case of grades with Ni content of 20÷40 wt%. It can be seen that cermets with 40 wt% of nickel have even better erosion resistance than cermet possessing a higher hardness and 30 wt% of binder.

5. THERMAL PROPERTIES OF CHROMIUM CARBIDE CERMETS

For high temperature applications the thermal properties such as coefficient of thermal expansion (CTE, K^{-1}), thermal diffusivity, thermal conductivity coefficient (λ, $Wm^{-1}K^{-1}$), and thermal shock resistance are important.

Mismatch in coefficients of thermal expansion of components results in thermal stresses during heating and cooling. CTE of pure Cr_3C_2 for temperature range 20÷1000ºC is about 11.7 $K^{-1}\cdot 10^{6}$. CTE of Ni is temperature dependant and is shown in Fig. 6. Cermets with higher Ni binder content have higher CTE.

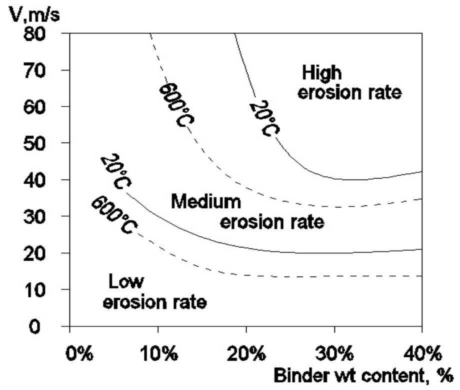

Figure 5. Erosion rate map. Impact angle is 90º. Abrasive-silica with main diameter 0.2÷0.6mm. Carbide particle size 3.0÷9.0μm. Porosity – about 1%.

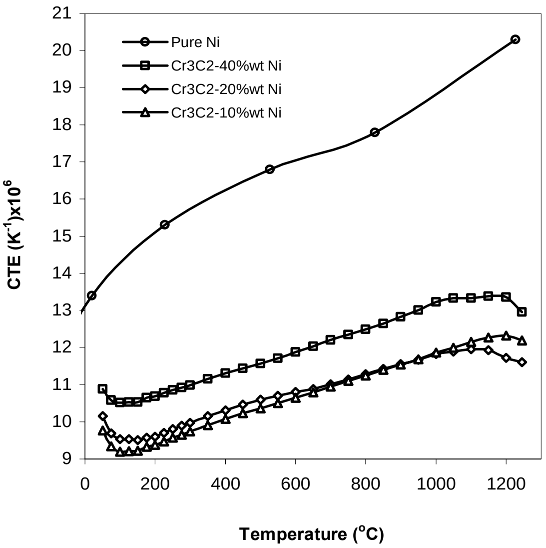

Figure 6. Effect of temperature and composition on coefficient of thermal expansion of pure Ni (Kaye & Laby, 1995) and chromium carbide cermets. Accuracy is about ± 0.9 for presented cermets.

The coefficient of thermal diffusivity (a) and specific heat (c_p) were used to determine coefficient of thermal conductivity (λ): $\lambda = c_p \cdot a \cdot \rho$, where ρ is a material density. In order to determine the thermal conductivity with a great accuracy in wide temperature range from room temperature up to 1500^0C, the diffusivity was measured with a laser flash apparatus combined with a IR – sensor by Differential Scanning Calorimetry method.

Thermal conductivity of pure Ni is higher than that of cermet or chromium carbide. It is about 94 $Wm^{-1}K^{-1}$ at room temperature and decrease slowly with temperature rise up to 67 $Wm^{-1}K^{-1}$ at 300ºC and then increase monotonously to 71 $Wm^{-1}K^{-1}$ at 700ºC (Kaye & Laby, 1995).

Influence of temperature on thermal conductivity is presented in Fig. 7. Coefficient of thermal conductivity of cermets with higher binder metal content rises more intensively with temperature increase.

To evaluate the effect of thermal stresses on crack formation, cermets have overcome thermal shock testing. Test samples were heated up to 1200º or 800ºC with heating speed of 400ºC/min and cooled in water or air medium. Tests were repeated until complete fracture of material.

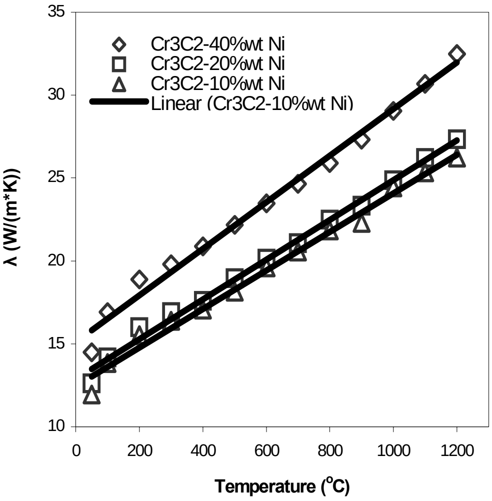

Figure 7. Effect of temperature and composition on thermal conductivity of chromium carbide cermets. Accuracy is about ± 1.5.

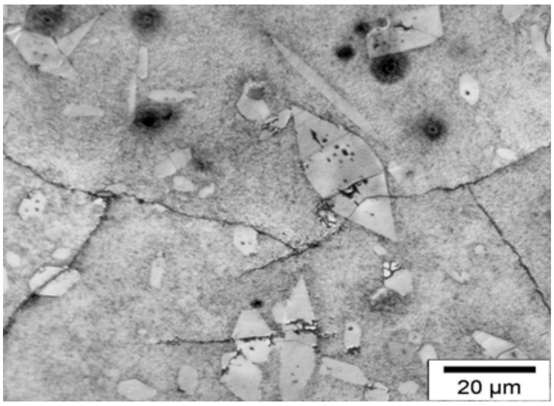

Figure 8. Cr_3C_2-10%wt Ni cermet after cycle 1200 ºC →water.

High resolution optical photographs (Fig. 8) allow to see that large carbide grains are sources of cracks even after 1 cycle. It was found that the presence of large Ni zones makes it possible for specimens behave as one piece even after 650 the most severe cycles 1200 ºC → water (Fig. 9). Nickel matrix prevent from the crack propagation. No differences were found for tests with different heating temperature 800ºC and 1200ºC.

The shape and the size of specimens have great effect on thermal shock resistance. This is due to high thermal gradient in large, thick and difficult form specimens. Large specimens have more possibilities to break down than small ones. Partial immersion is found to be more effective to crack formation and may be used as fast ways for determination of thermal shock/cycling properties.

The effect of higher thermal expansion of cermets with large binder content on surface crack formation during heating and cooling (cooling has greater effect due to tension stresses in carbides) is supposed to be partially compensated by their higher thermal conductivity. No noticeable difference in material behavior with different matrix content was found.

6. CONCLUSIONS

1. Cr_3C_2 based materials could be used in corrosion-erosion conditions at temperatures near 800ºC. Further increase in temperature leads to more severe oxidation (10 times per every 100ºC).
2. Erosion maps are constructed and analysis on their basis is made.
3. No noticeable difference in behavior of material with different matrix content during thermal shocks was found. One of explanation of such phenomena is simultaneous increase of CTE and accompanied decrease of thermal conductivity with Ni matrix content increase. More precise thermal testing with determination of mechanical properties after quenching is needed.
4. The presence of large elongated carbide grains in microstructure of cermets has negative impact into mechanical properties. Refined structure is found to be more favorable.

Figure 9. Cr_3C_2-10%wt Ni cermet after 650 cycle 1200 ºC →water.

ACKNOWLEDGEMENT

This work was supported by Estonian Science Foundation under grant N5882MT and EC-Program "Improving the Human Research Potential". The authors would like to appreciate the staff of Aerospace Materials Technology Testhouse for excellent work on sample analysis.

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