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VERIFICATION OF NEW 1000 °C TESTER DESIGNED FOR INVESTIGATION OF WEAR-CORROSION PROPERTIES OF ADVANCED MATERIALS FOR HIGH TEMPERATURE APPLICATIONS

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Abstract: *The high efficiency of thermal processes in energy applications is available at higher temperatures.*

The new tester for determination of wear and corrosion properties at temperatures up to 1000 °C was designed and built in Tallinn University of Technology.

The chromium and titanium carbide based cermets with various binder content and AISI 316 stainless steel were selected for verification of the designed rig as well as they have good oxidation and wear resistance (cermets).

The built map is showing the behaviour of materials with various metal binder content and under various oxidation-abrasion conditions is a good tool for industrial engineers for minimizing of materials loss and to increase the lifetime of the components.

Key words: High temperature, Cermet, Abrasion, Oxidation, Mapping.

1. INTRODUCTION

The high efficiency of thermal processes in energy applications is available at higher temperatures. As well as there is a contact of parts, the wear in contact zone could not be excluded and should be controlled. The corrosion as well as oxidation is increased at higher temperature. The wear and corrosion under some conditions can cause the accelerated degradation of materials [1].

The cermets that are developed and produced in Tallinn University of Technology (TUT) are promising materials for high temperature applications were resistance to corrosion and wear properties are of high importance [2]. At the present time for testing of materials at high temperatures in TUT there is only erosion test rig that enable to make testing at temperatures up to 700 ºC with impact angle between 30º and 90º [3]. However, the conditions were the angle is close to 0º are more often presented and observed in during interaction of abrasive particles in gas or particle flow [4].

In order to make the testing of materials at temperature reaching 1000 ºC the new erosion-abrasion tester was developed, manufactured and tested. The tester was designed to make possible to test several samples in the conditions of two abrasives at the same time. This gives the possibility to test the developing material and well known one under the same conditions and to make comparison on the basis of the relative wear rates. The parts of the tester, which experience high wear rate, are made exchangeable.

2. DESCRIPTION OF THE TESTER

The test is run in two chambers with abrasive (6) that are heated in electrical oven (4) (design and designation of parts - see Figure 1). The samples (1) are fastened between disks (2). In total 18 samples could be tested in each chamber. The disks are rotated through the shaft (3) by the electrical motor (7) with reduction gear (8). The reduction gear is used to make testing at very low frequency of rotation to see the interaction between oxidation and wear.

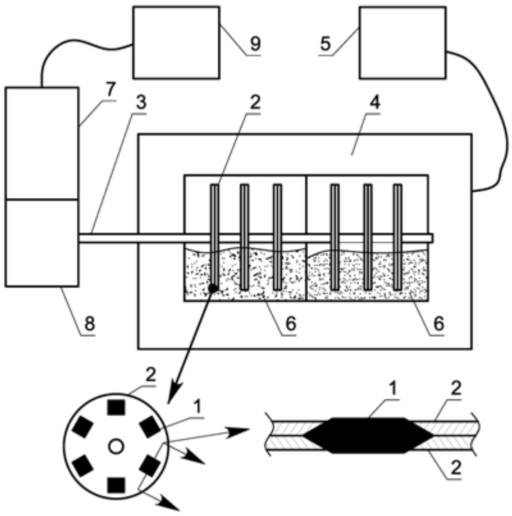


Figure 1. Scheme of the high temperature multi sample, two chamber abrasion tester. Explanations – see the text.

Chamber temperature (5) and motor frequency (9) controllers are used to apply the required test conditions.

The disks, chamber and shaft are made of 1.4746 (DIN X8CrTi25) heat resistant steel with good welding properties. Maximum service temperature is 1100 ºC

The supporting area of bearing places is increased to diminish the wear; the design is made to protect it from abrasive.

The bolts that are used to gripe the disk pairs (not shown on scheme) are used for one test only.

The rotation of the disk does not create vibration as in previous single specimen oscillating type of high temperature wear tester. Also there is no measurable crushing of abrasive [[5]].

The main features of the test rig are presented in Table1.

3. TEST CONDITIONS

Several cermet grades and one stainless steel were tested at high temperature under conditions of oxidation (no abrasive) and combined oxidation – wear with two different wear intensities (frequency of disk rotation) with two abrasives. The main test conditions are presented in Table 1.

Table 1. Main design features and working parameters of tester

Feature / parameter	Description	
	Available	**Tested**
Size of one chamber (L x W x H), mm	125 x 120 x 120	
Diameter of disk / specimens centre location, mm	105 / 77	
Size of specimen (L x W x H), mm	25 x 15 x 5	
Area of specimen subjected to wear, mm^2	45	
Area of specimen that is not subjected to wear, mm^2	48	
Frequency of disk rotation, min^{-1}	1 - 25	3.3, 13.3
Speed of specimen movement, m s^{-1}	0.004 – 0.1	0.01, 0.05
Number of specimens tested in one chamber	3 x 6 = 18	1 x 6
Number of chambers with abrasive	2	2
Temperature, ºC	20 - 1000	900
Environment	Air	

The conditions were chosen to see the effect of wear on resulting degradation rate at high temperature. The materials tested are presented in Table 2.

Table 2. Materials tested

Designation	**Composition wt %**	**Hardness HV**
C10	$90Cr_3C_2$ – 10Ni	1490
C15	$85Cr_3C_2$ – 15Ni	1410
CK20	$80Cr_3C_2$ – 16Ni 4Cr	1500
T20	80TiC – 16Ni 4Mo	1515
C40	$60Cr_3C_2$ – 40Ni	900
A	Conventional AISI 316	175

Table 3. Abrasives

Property	SiO_2	SiC
Size, mm	0.2 – 0.4	1.0 – 2.0
Hardness, HV	1100	3000
Shape	Rounded	Angular

Cermet materials were fabricated at Tallinn University of Technology using a conventional P/M technique. The carbide grain size was 2 – 8 µm.

Sand and silicon carbide were used as abrasives for the current study. Sand was chosen as the most often occurring abrasive. Silicon carbide was chosen for its higher hardness and more angular shape. The basic properties of the abrasives are presented in Table 3.

The duration of tests was 4 hours for oxidation, 4 hours for wear at low speed and 2 hours for wear at elevated speed.

4. TEST RESULTS

The weight of the specimens before and after the test was measured with the help of *Mettler Toledo* electronic scales with 0.1mg accuracy and the weight change calculated. Test results are presented in Table 4. It is possible to see that all materials have exhibited the weight gain during oxidation. However, when the wear is acting in parallel, the decrease of mass is also observed.

Due to the presence of zones on sample that are subjected either to oxidation only or to oxidation and wear the decrease of weight should be corrected to show the data on high temperature wear properties.

Table 4. Decrease of specimen's weight during testing (oxidation - W_O, abrasion - W). Weight is given in milligrams.

Conditions / Grade	C10	C15	CK20	T20	C40	A
Oxidation	-1.15	-1.20	-1.75	-36.85	-1.45	-1.60
Abrasion, SiO_2, 3.3 min^{-1}	0.60	0.50	0.70	0.00	-2.30	3.00
Abrasion, SiO_2, 13.3 min^{-1}	-0.20	-0.60	1.30	3.80	-2.20	19.70
Abrasion, SiC, 3.3 min^{-1}	0.00	0.00	-0.80	10.10	-1.30	-1.50
Abrasion, SiC, 13.3 min^{-1}	0.00	-0.70	-0.90	6.90	-1.50	9.30

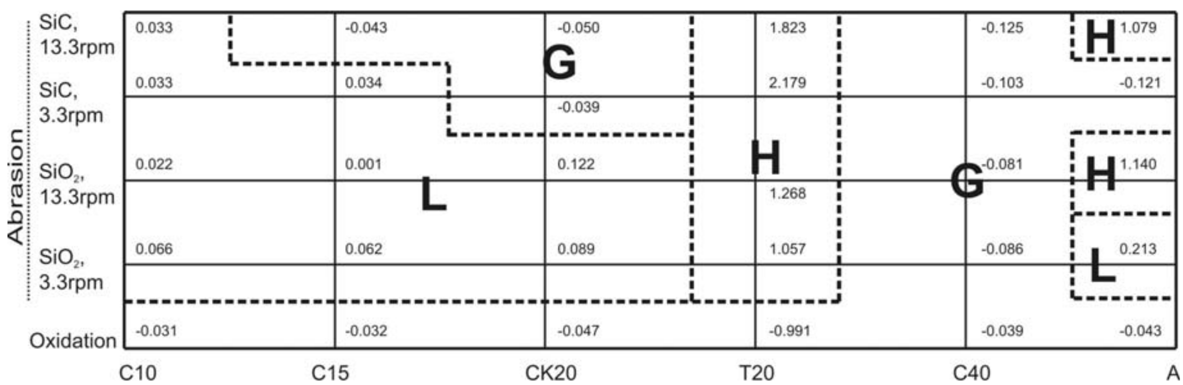


Figure 2. Mapping of the effect of binder content (material) and conditions on material degradation under conditions of oxidation and high temperature abrasion. Weight decrease rate (oxidation - K_O, abrasion - W_{AO}) is given in mg cm^{-1} h^{-1}. Explanations – see text.

The equation for the calculation of the wear rate at high temperature for the designed tester is:

$$W_{AO} = \frac{W - (A_{OO} K_O t_{AO})}{A_{AO} t_{AO}} \qquad (1)$$

$$K_O = \frac{W_O}{A_O t_O} \qquad (2)$$

where:

A_O - area of the whole sample subjected to oxidation test, 9.3 cm^2

A_{OO} - area of the sample subjected to oxidation during wear test, 4.5 cm^2

A_{AO} - area of the sample subjected to abrasion and oxidation during wear test, 4.8 cm^2

K_O - weight decrease rate due to oxidation only, mg cm^{-1} h^{-1}

t_O - duration of the oxidation test, h

t_{AO} - duration of the wear test, h

W_O - weight decrease during the oxidation test, mg

W - weight decrease during the wear test, mg

W_{AO} - wear rate (weight decrease) at high temperature corrected for the designed tester, mg cm^{-1} h^{-1}.

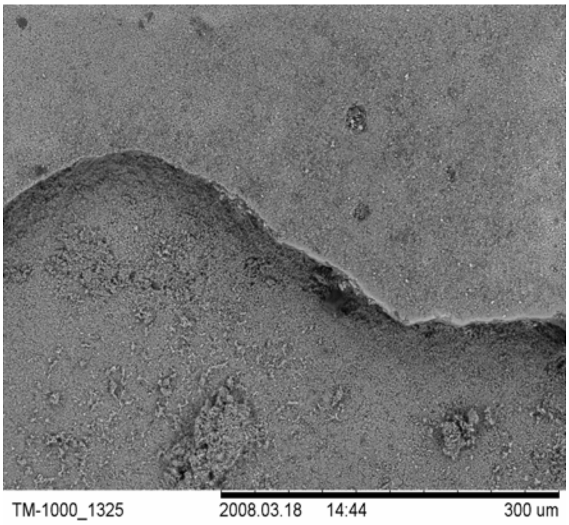
The results on weight decrease rates during wear and oxidation tests are presented in the form of map (Figure 2).

The zones showing material behaviour are designated as following:

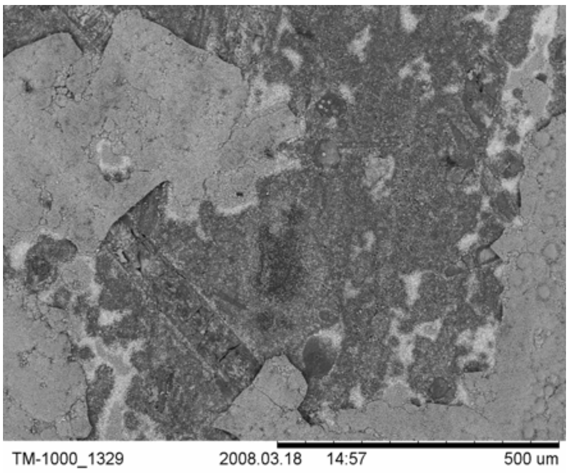
G – the material exhibit weight gain
L – the wear is between 0 and 1 mg cm^{-1} h^{-1}
H – the wear is higher than 1 mg cm^{-1} h^{-1}

Low binder cermets have low wear rate. The wear rate of low binder Cr_3C_2-Ni cermets and stainless steel is higher during abrasion with silicon carbide. Chromium carbide based cermet with high binder content has shown the mass gain under all conditions tested. The pronounced sticking of abrasive particles to the material surface is the reason of that [5]. Unfortunately the TiC –Ni Mo cermet with tested composition has shown the lowest resistance to wear at high temperature. The stainless steel has shown the well pronounced increase of wear rate with the increase of speed of specimen movement with both abrasives.

The high wear rate of titanium carbide based composite could be explained by the formation of the thick, continuous and easily removable during abrasion oxide layer (Figure 3). On the other hand, the continuous layer on the surface of low binder chromium carbide cermet is presented only in some places and it is much thinner. In other zones the surface consists of carbide grains and binder.



(a)



(b)

Figure 3. SEM micrograph of T20 (a) and C10 (b) materials.

5. DISCUSSION

It is favourable that it is possible to test as much as 18 samples of different materials and to calculate the relative wear resistance to compare the behaviour of new material under investigation with the conventional one. However, there are some difficulties if necessary to compare the behaviour of material at different velocities. At lower velocity it is possible to say that the abrasive grain that is pressed toward the disk is touching it during almost all of the disk (and specimen) turn. At higher velocity the abrasive is thrust away by the disk surface irregularities, specimens. So during some moments the abrasive particle is not working that reduce the efficiency.

It was found that the wear rate of some material could be with minus sign that means that they are gaining the weight instead of loosing it. This was found due to oxidation and the sticking of the abrasive particles to the surface. In order to overcome this test for materials behaving in this way should be prolonged at least three times.

6. FURTHER RESEARCH

More materials are to be tested, especially those cermets, that were developed in TUT for high temperature applications (with different carbide base, binder content and binder composition, production route).

During the rotation, the specimen is subjected to oxidation for some time and then to abrasion. The computer controlled step motor that is available will be used for creating more different testing conditions. These include the change of rotation direction, stopping inside the abrasive, moving only inside the abrasive without turning to the abrasive free area and so on.

The tests are to be done at various temperatures to see the effect of temperature (oxidation) on wear rate.

7. ACKNOWLEDGEMENTS

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