Friction and Wear of Materials: Principles and Case Studies
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Lecture –30
Erosive Wear of SiC - WC Composites

Okay, welcome all. In this lecture, we would like to see the salient results from the erosion studies of silicon carbide tungsten carbide composites so these composites were prepared with change in tungsten carbide content from 0 to 58%.

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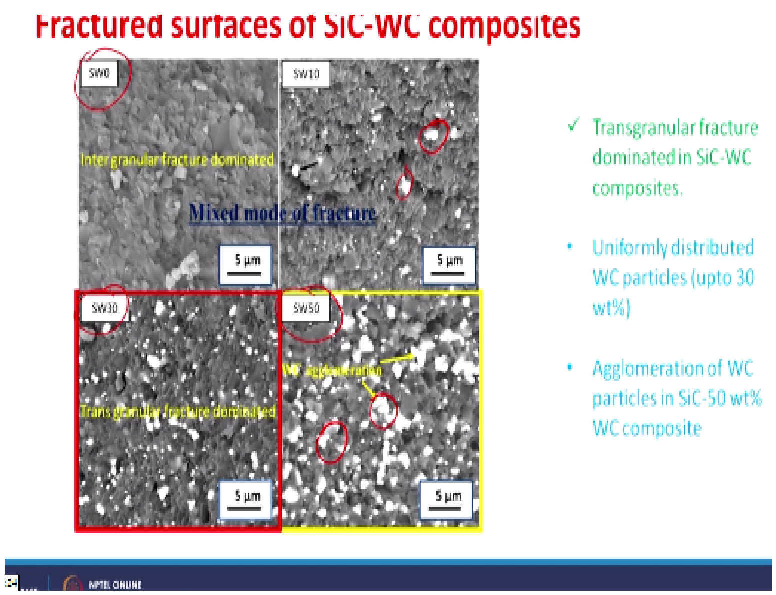

So SW0 means silicon carbide without any tungsten carbide as W10 means silicon carbide with 10 weight percent tungsten carbide 30 means silicon carbide with 38% silicon carbide 50 means silicon carbide with 58% tungsten carbide. So, these composites were prepared by hot pressing and the micro structures of the silicon carbide tungsten carbide composers after fracture appear like this.

So there is a inter granular fracture dominated for the silicon carbide without having any tungsten carbide content at the same time the transgranular fracture is dominating when the tungsten carbide content is increased so overall all the fracture occurs by both into granular and transgranular. The domination of inter granular is found in silicon carbide ceramics whereas the domination of trans granular fracture is found with increase in the tungsten carbide content in the silicon carbide ceramics.

So, in addition to that the tungsten carbide particles the white one and the tungsten carbide particles these are uniformly distributed in the SW 30 sample and you can also see the agglomerations of tungsten carbide particles in SW50 sample.

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Microstructural and Mechanical Properties of selected SiC-WC composites

Sample	Grain size (nm)	Inter particle distance (µm)	WC volume fraction	Hardness (GPa)	Fracture toughness (MPa m1/2)
SiC (SW0)	835±73	----	0	23.95 ± 0.97	5.85±0.30
SiC-10wt%WC (SW10)	724±65	6.805±2.763	0.08±0.01	24.02 ± 1.12	6.36±0.22
SiC-30wt% WC (SW30)	637±53	2.922±.667	0.28±0.01	26.33 ± 0.71	6.47±0.13
SiC-50wt%WC (SW50)	578±62	2.303±.395	0.46±0.01	24.26 ± 1.12	6.66±0.12

So, the micro structural investigation also shows that the average grain size decreased from 835 nanometers for the silicon carbide to 578 nanometers for the silicon carbide with 58% tungsten carbide the inter particle distance also decreases with the increase in tungsten carbide content and you see the hardness. The hardness is maximum for the SW 30 composite where there is a uniform distribution of the tungsten carbide particles in SiC matrix and the fracture toughness increases from 5.85 to 6.66 mph root meter with increase in tungsten carbide content from 0 to 58%.

So these composites were subjected to erosion. So, the erosion was carried out by using eroded particles of aluminium oxide or silicon carbide having a particle size range.

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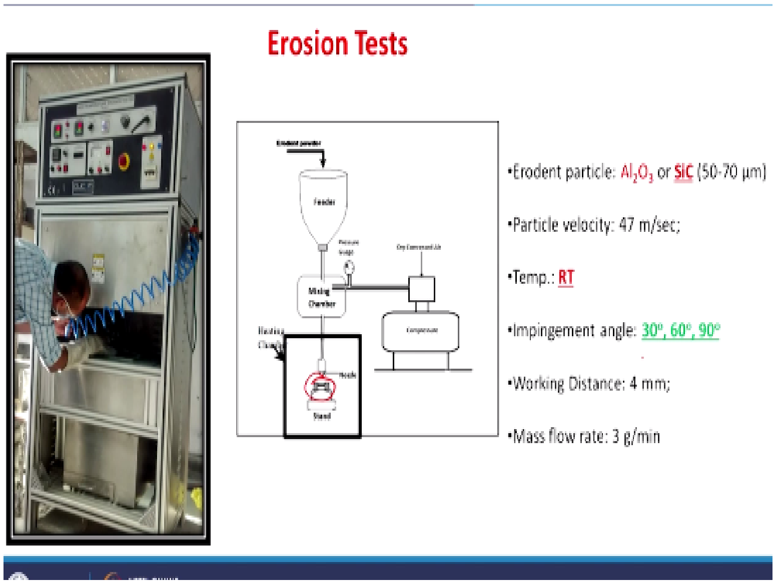

Between 50 to 70 micron meter so these particles were impinged at a particular velocity on the sample and the sample is stilted so that there is an impingement angle change from 30 to 60 to 90 degrees keeping a work hand distance of 4mm and keeping the mass flow rate of 3gram per minute. So, we conducted all these experiments for the composites at the room temperature initially then we also did at high temperature but initially the room temperature.

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Erosion Test Results

Sample	Erosion rate (mm^3/kg)	
	90° (alumina)	90° (silicon carbide)
SW0	18.31	1044.63
SW30	6.57	850.73
SW50	20.49	1223.24

Particularly at 90 degrees impingement angle can see the erosion test results. Erosion test results were actually like in terms of erosion rate is a volumetric material remote power the amount of the eroded used in the experiment. So, we used this erosion rate as a measurement for the erosion wear so we found a steady state condition in which the weight loss is consistent so in initial key stages of the erosion the weight loss increases.

And then after a certain time the weight loss does not change much so we found a suitable time where the weight loss reminds a constant so we call it as a study state. And we selected the times such that the steady state is a present for a considerable time so the weight loss which can be taken as a characteristic measure of the material in the erosion conditions the weight loss is converted to volumetric loss.

Because we know the density so and then the volumetric loss divided by the amount of erodent used so we get an erosion rate. So, at 90 degrees angle alumina when alumina erodent is used can see this silicon carbide with tungsten carbide composites they have erosion rate changing from around 7 to around 20 mm cube per kilogram whereas silicon carbide. You can see is you can see it is varying from 850 to 1223 mmcube per kg.

So, first of all there is a larger difference between the erosion rate for the ceramic composites eroded by alumina and eroded by silicon carbide and the erosion rate absorbed when erodent of silicon carbide was used was very high so it is almost to 2 orders of magnitude higher than that obtained using alumina erodent and in addition to that we also can find these SW30 shows minimum erosion rate either alumina erodent condition or silicon carbide erodent condition.

So, we got the minimum wear for the SW30 so SW30 which is silicon carbide with 30 weight percent tungsten carbide composite which has a uniform distribution of these tungsten carbide particles and also exhibited a higher hardness so you can see this.

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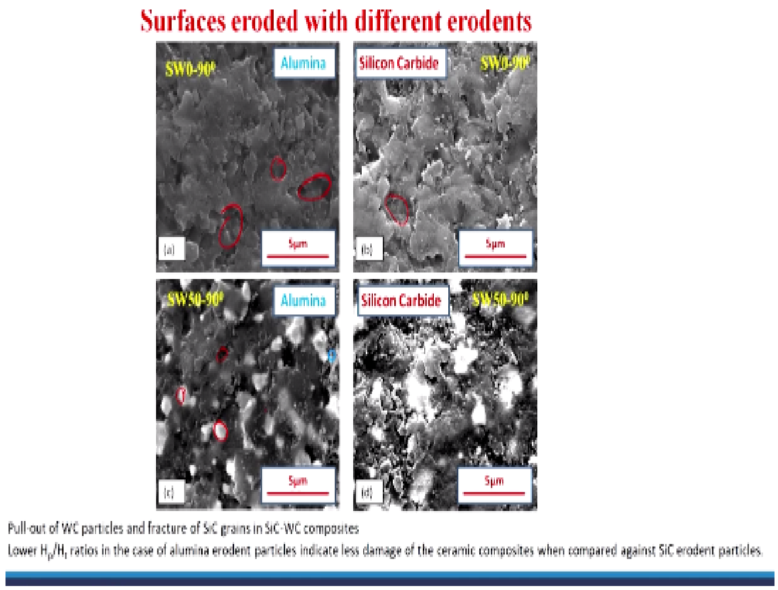

The surface is after erosion with different erodent at this 90 degrees angle so the pull out is generally absorbed because this is a ceramic material so at 90 degrees there is a large amount of fracture occurring and this leads to the material removal. So, the silicon carbide ceramic are the silicon carbide tungsten carbide composites they are reordered mainly by the pull of this particles of particles or the grains the pullout of tungsten carbide particles can be seen.

In the composite can see the particles are removed from the surface whereas the removal of the silicon carbide grains also absorbed so in both cases the particles are remote or fractured are the grains of silicon carbide are removed or fractured. So, the material is removed mainly by the mechanical aspect so one more important observation from this study is the alumina having relatively lesser hardness than the silicon carbide.

So, it is actually giving a lower erosion when use the silicon carbide so if you take the hardness ratio of hardness ratio of erodent to the target material the hardness ratio lower ratios of these particle to target in case of alumina erodent particles indicates less damage of the ceramic composites. When compared agonist to the silicon carbide erodent particles so this part of the study particularly shows there is an effect of the erodent used or in other words, there is an effect of the hardness of the erodent used on the material removal in the erosion conditions.

We did this silicon carbide tungsten carbide composers erosion study at high temperatures because these composites are attractive materials for high temperature erosion conditions. So, it is very interesting to understand the erosion behaviour at high temperature the same setup.

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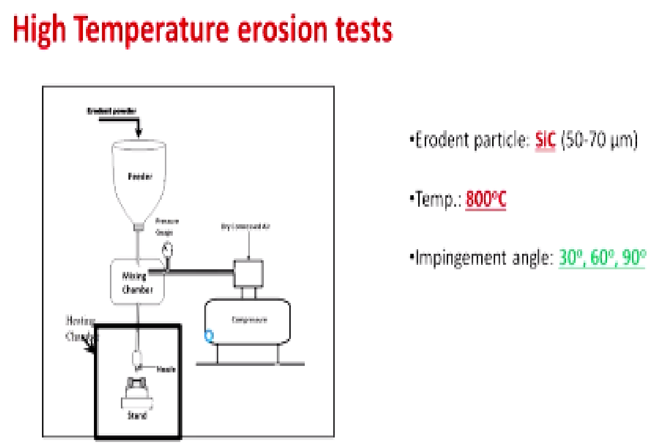

For this erosion study we use the silicon carbide particle only because now we came to know that silicon carbide only gives the maximum erosion then the alumina so our idea is to understand the material removal. When they were subjected to severe conditions of the erosion so erodent particle SiC was used so this erosion was done at a high temperature of 800 celsius with a change in angle now let us see the erosion rate so again the weight loss measurement was used.

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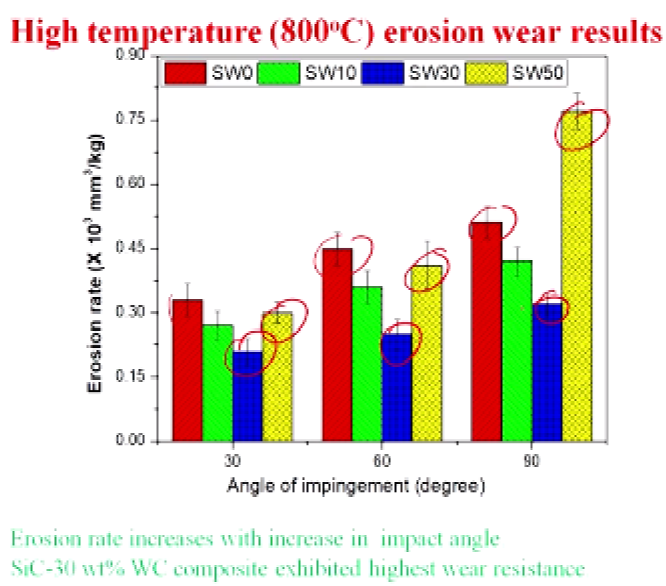

And then we can converted into volumetric loss and divided by the erodent used the amount of erodent used to get a erosion rate so if you see here with the increase in angle for any material either it is silicon carbide or silicon carbide tungsten carbide composite. There is an increase in the erosion rate with angle the erosion rate increases so it is generally understood for a brittle material when the angle is at higher.

Then there is a lot of cracking occurring that cracking leads to the fracture and then material removal compared to that from the lower angle conditions so similarly the erosion rate for these materials also increases with the impact tangle with respect to the composition the silicon carbide 30% tungsten carbide composite always exhibited lower erosion rate. So, at any angle of impingement this SW30 exhibited lower erosion rate.

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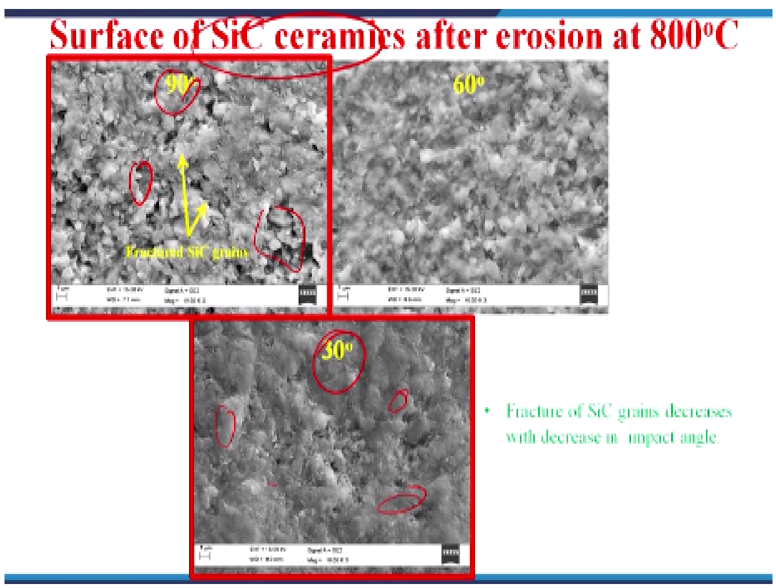

So, let us understand this by observing the surfaces of the ceramic composites after this erosion so after erosion silicon carbide without having any tungsten carbide so it just to showed the fracture of the silicon carbide grains. But the fracture actually decreased from 90 degrees to 30 degrees so we can see certain deformed grains or the compacted grains which are deformed yet lower angle whereas a large amount of fracture occurring at the higher angles.

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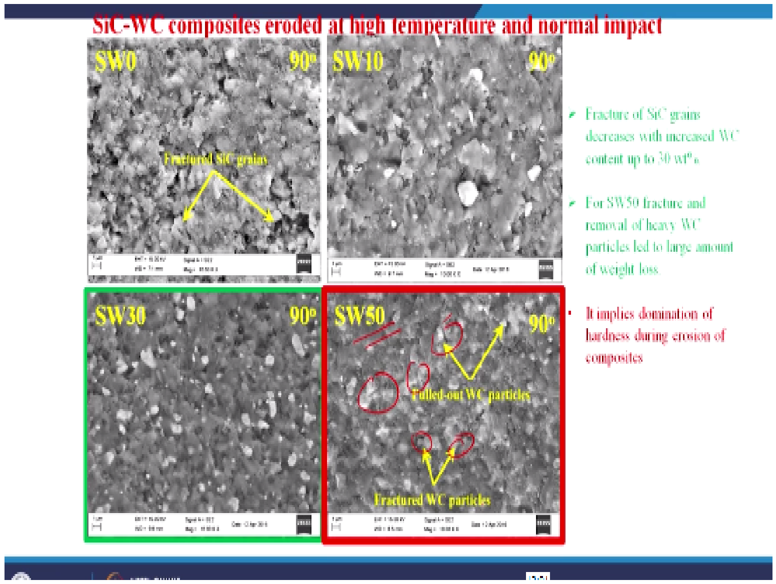

So, similarly for the composites silicon carbide tungsten carbide composites those were eroded at that high temperature and then at normal impact again the fracture of the silicon carbide grains decreased with the increase in the tungsten carbide content from 0 to 58% and but the fracture is the fracture actually decreased up to 38% and after this 38% 50% containing 50% tungsten carbide containing silicon carbide showed more amount of removal.

So, you can see the of these tungsten carbide particles on the fracture of these tungsten carbide particles and the particles are more or less like agglomerated things so if you can remember our fracture surface of this material. This material particularly has the agglomerated tungsten carbide particles in a matrix of silicon carbide so tungsten carbide being very heavy if the material removed is more or less like agglomerated.

Agglomeration of number of tungsten carbide particles the weight loss will be also very high remember these experiments were done at high temperature. There is already a thermal stress generated and the thermal stress generated these thermal stresses will be high at those defects sites of agglomerates of tungsten carbide particularly in this SW50 there it was a large amount of agglomeration.

So, the highest thermal stress concentration at the defect the sides of this agglomerates of tungsten carbide lead to the high erosion wear. So, you get the maximum ware for the ceramics having this kind of agglomerated mike tungsten carbide particles so the fracture of these grains decreased with increase in tungsten carbide content but the decrease is restricted up to the 30%tungsten carbide containing ceramic composites.

So, it implies actually the domination of hardness during erosion of composites so if you can remember the hardness data the harness was also very high. Among the investigated composites the hardness was high for the SW30 around 2060 gigapascals whereas others have around 23 to 24 gigapascals so that uniform distribution of these tungsten carbide particles resulting into a higher hardness and the higher hardness actually led to the lesser amount of material removal in this erosion conditions.

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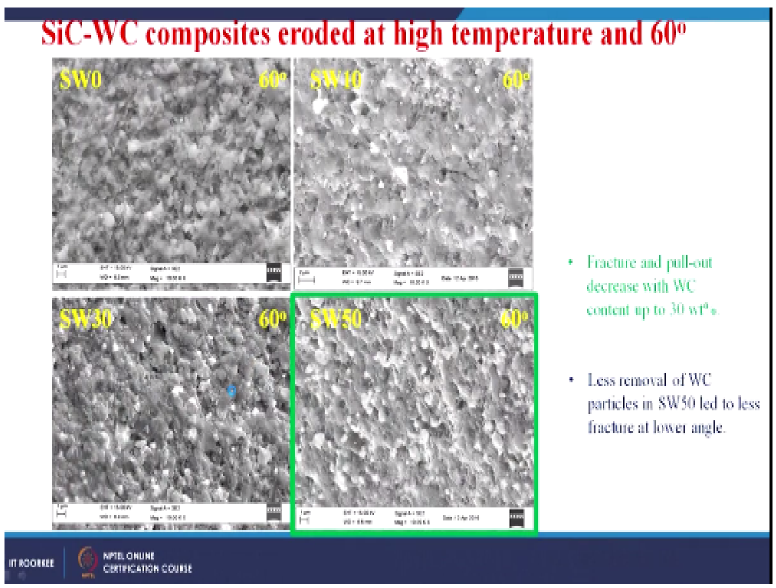

So, the fracture and pullout decrease with the tungsten carbide content up to 38% even at other angles less removal of tungsten carbide particles in these SW50 led to the less fracture at the lower angles that when you compare with the with respect to angle again the same the fracture induced maximum wear at the highest angle.

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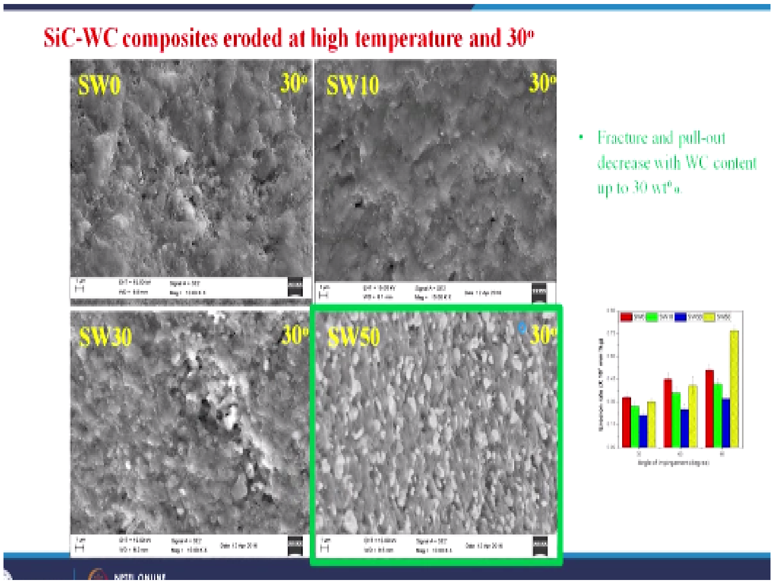

So, again you can see this 30degrees angle again the fracture is minimum for the SW30 whereas a lot of tungsten carbide particles are removed. And then they fractured the grains are fractured at tungsten carbide particles are fractured at for the SW50 so compared to again 90 degrees so the fracture is less for any given composite.

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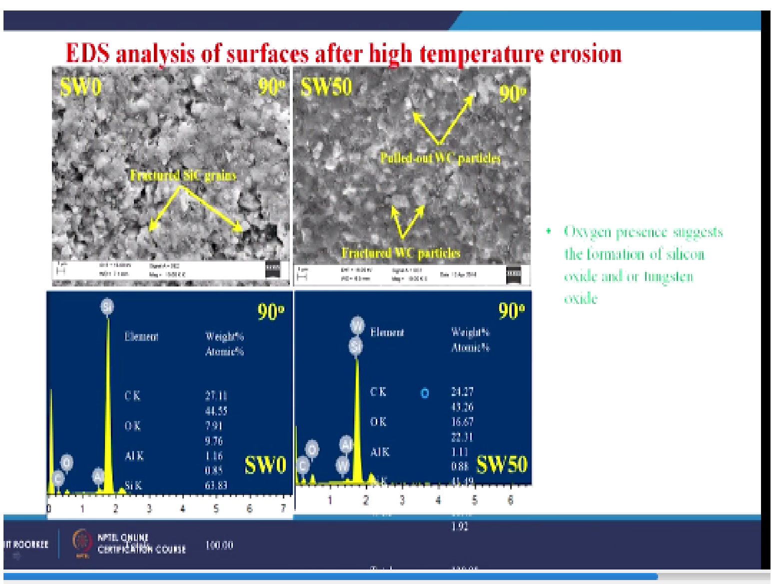

EDS analysis of these composites after high temperature erosion show there is a presence of oxygen in addition to the silicon or the tungsten so this indicates there is a formation of oxides of silicon or tungsten on the eroded surface.

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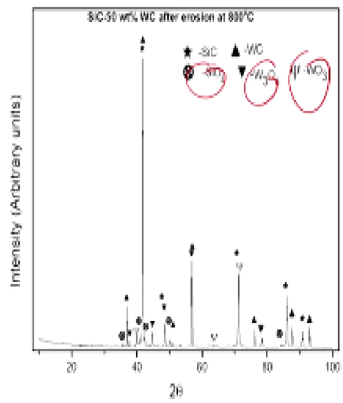
XRD analysis of composite after high temperature erosion



Proposed reactions for oxide formation:

$SiC\,(s) + 2O_2\,(g) = SiO_2\,(s) + CO_2(g)$

$2\,WC(s) + 5\,O_2(g) = 2\,WO_3(s) + 2\,CO_2(g)$

$3\,WC(s) + 7\,O_2(g) = W_3O_8(s) + 3\,CO_2(g)$

So, we also conducted an x-ray diffraction analysis of this composite surface composite after this high temperature erosion these shows silicon carbide tungsten carbide and also the oxide of silicon tungsten so several oxides of these silicon are tungsten are available on the eroded surface. So, this is also in agreement with the EDS analysis so it actually indicates there is an oxidation at high temperature and then this oxide surface when subjected to erosion.

So, there is an increased amount of oxide and which are predominantly present on the oxides on the eroded surface so this erosion is influenced by these oxides which are formed at the high temperature. So, let us conclude these results the erodent particle hardness significantly have affected the time required for reaching the steady state as well as the extent of material removal for the investigators silicon carbide tungsten carbide composites.

In the silicon carbide tungsten carbide composites show improved via resistance at higher temperature with reinforcement of tungsten carbide particles up to 30 weight percent.

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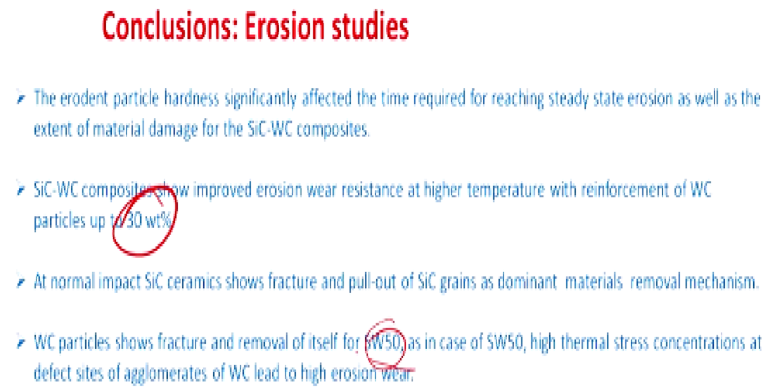

So at normal impact. These ceramic show fracture and pull out of the grains as dominant material remove mechanisms whereas when you have the tungsten carbide but also in the micro structure first the tungsten carbide particles are removed. Then fractured followed by the fracture of the silicon carbide grains are they removed so tungsten carbide particle so fractured and removal of itself for these composites particularly when the tungsten carbide content is high then you have large amount of these particles removal in terms of the agglomerated agglomeration.

So, when you have agglomerated sites those are actually sites for the higher stress concentrations. So, up to 30 weight percent tungsten carbide silicon carbide ceramics composites show higher wear resistance in the investigated erosion conditions. Thank you, let us continue this with the next session.