A review on the performance of reinforcements at elevated temperatures

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Abstract

This type of the material degradation has become major problem in many industries including power plants (thermal and nuclear), steam generators, cement industry, turbine engines, and garbage incineration. A big gap still exists between understanding of influence of the temperature on erosion performance at the elevated temperature between the experimental observations up to 1100°C and elevated temperature in the industrial applications where temperature touches 1400°C. The main focus of this article is to review the solid particle erosion behavior and mechanisms of ceramics under elevated temperatures upto 1400°C so that new materials can be developed to combat the erosion at elevated temperatures.

Keywords: High-temperature, Turbocharger, Alloy-718/NiCrAlY, HVOF, Grey cast iron.

1. Introduction

The material degradation has become major problem in many industries including power plants (thermal and nuclear), steam generators, cement industry, turbine engines, and garbage incineration [1-4]. The main difference between erosive wear and other type of wears is that in erosive wear the time of contact between particles and surface is momentary but in sliding wear there is a continuous contact between particles and target surface [5]. Erosive wear is considered to be as the major factor for down time in boilers because during burning of coal ash is produced and on an approximate 20% of this get deposited on tubes of the boilers, economizers and will discharge as slag & clinker during soot blowing process. Remaining ash will entertain in the stream of flue gas leaving the boiler. These ash particles strike on the surface of boiler components and cause erosion [6]. The damage of boiler tube due to erosive wear. The thickness of the boiler tube is reduced so much that it will no longer contained hoop stresses and will burst leading to the failure of the tube [7] and maintenance expenses (damaged tubes) can rise up to 54% of the total production cost[8].
2. Failures at elevated temperatures

Life of the component at elevated temperatures decreases due to activation of different failure mechanisms. In general there are five major factors that were considered to be responsible for failure of a component according to total productive maintenance method (TPM)[10]. However failures at elevated temperatures proceed gradually. There are two stages known as primary and secondary. In the primary stage there is just an initiation of failure or failure is hidden but after some time so called secondary stage tries to dominate in which there are clear signs of failures on components surface. Depending upon the nature of damage, type of failure mechanism and keeping in view the condition of the structural component there exists a period known as reaction period during which an action need to be taken for the maintenance of the damage component before major break down. Different stages of failure propagation are shown in figure. 4. It is clear that sum of time for inspection frequencies and time reserved for repair should be less than the reaction time from the observation of a failure to breakdown. Moreover time for inspection frequencies varies from component to component. Also it is to be noted that when any component fails as a result of damage or fracture, detailed study of the failure mechanism is to be done so that failure in future from same causes can be prevent.

Therefore it becomes necessary to predict the erosive wear rates in elevated temperature applications so that planning can be done for the maintenance of the components. Erosion resistant materials at high temperatures can enhance the useful life of the components. Materials such as ceramics are of great interest because of their thermal, chemical and mechanical performance that makes them suitable candidate to meet engineering requirements. One such application of ceramics involves the protection of structural components against erosive wear at elevated temperatures. This section covers effect of elevated temperature on performance of the some ceramics.

3. Performance of some ceramics at elevated temperatures of 1400°C

Authors have reported that erosion rate was minimum at 30° impact angle with temperature of 1200°C due to the enhanced mechanical properties, less porosities and phase composition. CCB has least erosion rate than its counterparts due to alumina percentage and better mechanical properties. Material removal mechanism involved was mainly chipping of aggregates and binder phase along with fracture and also by aggregate pull-out. Brittle mechanism of erosion is still dominating these hard refractoriness at high temperatures due to solid particle impact[9].

Erosion rates for RT and 800°C has a gradual increase in curve and maximum erosion takes place at 90° that was true in contrast with literature findings that for brittle materials such as ceramics maximum erosion takes place at normal impact angles. While for the temperatures of 1200 and 1400°C maximum erosion takes place at angles of 60 and 75° which was also reported by some investigators [10-15]. Major reason for this is that at high temperatures strength and hardness of alumina ceramics drops significantly that result in more damage to samples. Brittle mechanism of erosion is still dominating at high temperatures again.

This exhibits that for higher temperatures erosive wear resistance can be improved. Maximum erosion takes place at 90° impact angle which can be related to brittle nature of ceramics. In another high temperature erosive wear investigation studied the
effect of silicon addition in different quantities in mullite SiC composites at 90°C [16]. It was observed that erosion rate increases with increase in temperature up to 800°C for all compositions but after that erosion rate continues to decrease up to 1400°C. Maximum erosion resistance was given by 12%Si. Once again plastic deformation was found to be main reason for low erosion rates at high temperatures.

The effect of elevated temperature on the performance of 5YSZ ceramics at 90° impact angle. Investigators reported that erosion rate increases gradually from RT to 600°C and after that up to 1200°C it increases rapidly. As the temperature increases hardness and toughness of ceramics decreases resulting in formation of wide cracks and consequently these cracks with increase in temperature crisscrossed together which was the main erosion wear mechanism responsible for loss of material between 600-1200°C. In general plastic deformation mechanism was also noted form RT to 1400°C along with main erosion wear mechanism. Decrease in elastic modulus after 1200°C was the main factor responsible for decrease in volume erosion rate of 5YSZ at higher temperatures (1400°C). Effect of temperature on the volume erosion rate of 5YSZ ceramics is shown in Figure.1.

![5YSZ](image)

**Figure.1.** Effect of temperature on the volume erosion rate of 5YSZ ceramics.

4. **Comparison at elevated temperatures (1400°C)**

In this section performance of the ceramics discussed earlier are compared with respect to the elevated temperature range (°C) vs erosion rate (mm³/g). As shown in graph in fig. 8, it was clear that 5YSZ ceramics exhibits better performance at 1400°C to erosive wear than other three materials due to decrease in value of elastic modulus of ceramics. It was also found that chrome corundum brick (CCB) shows negative rate in erosion due to adhering of erodent particles on the eroded samples that result in mass gain
followed by negative erosion rate and same can be ignored. The superalloys can be utilized for the deposition of coatings to combat hot-corrosion [24-28].

Table 1
Overview of the studies performed on ceramics, at elevated temperatures upto 1400°C[ 16-23].

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Year of publication</th>
<th>Authors</th>
<th>Substrate</th>
<th>Testing Temperature</th>
<th>Angles</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2012</td>
<td>Yang, JZ, et al</td>
<td>3 types of alumina based [HAB, CMB &amp; CCB] refractories</td>
<td>Up to 1400°C</td>
<td>30, 45, 60, 75 &amp; 90°</td>
<td>All three types shows increase in erosion resistance with increase in temperature and decrease of angles. Erosion rate was minimum at 1200°C &amp; 30° impact. CMB was better than other two due to its good mechanical properties.</td>
</tr>
<tr>
<td>2.</td>
<td>2013</td>
<td>Wang, X, et al</td>
<td>Alumina ceramics</td>
<td>Above 1100°C</td>
<td>30, 45, 60, 75 &amp; 90°</td>
<td>Erosion rate was strongly dependent on temperature. Up to 800°C erosion rate increases slightly and maximum erosion occurs at 90°. Above 800 erosion rate curve rises sharply and for 1200 &amp; 1400°C maximum erosion occurs at 75 &amp; 60° that indicates brittle behavior of ceramics.</td>
</tr>
<tr>
<td>3.</td>
<td>2014</td>
<td>Li. X, et al</td>
<td>SiC-Si₃N₄</td>
<td>Up-to 1400°C</td>
<td>30 to 90°</td>
<td>For all angles erosion rate increases up-to 800°C. Erosion rate was minimum at 30° impact angle &amp; 1400°C due to formation of thin dense glass film and enhanced bonding strength between coarse aggregate and ceramics.</td>
</tr>
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</table>
5. Conclusions

Solid particle erosion is a challenge problem to solve at high temperatures especially in the area where temperatures are in the range of 850ºC-1400 ºC. Performance of materials at elevated temperatures is affected by several factors like impact angle, erodent characteristics and impact velocities. It was also found that chrome corundum brick (CCB) shows negative rate in erosion due to adhering of erodent particles on the eroded samples those results in mass gain followed by negative erosion rate and same can be ignored.

References