VINOD KUMAR M. S
R. SURESH
and
N. JEGADEESWARAN

Study of solid particle erosion of thermal spray coated and uncoated cobalt based superalloy

Erosion resistance of turbine components can be improved using various thermal spray coatings techniques, in the present work HVOF spray coating technique is used to deposit tungsten carbide alloy powder composition (30%WC-CO+70% NiCrBSi) on cobalt based seperalloy Superco-605. The coating is characterized using scanning electron microscope (SEM). Solid particle erosion behaviour of coating is evaluated at 30º, 60º and 90º angle of impact at room temperature, silica sand of size 150µm is used as erodent, particle feed rate maintained is 4.8gm/min, rate of erosion and steady state volumetric erosion rate is determined and results are plotted, from the plots it is indicating that the rate of erosion for coated samples are higher compared to uncoated samples, and there is higher erosion rate at 90º angle of impact and tends to be low for impact angle of 30º indicating brittle mode of erosion.

Keywords: Erosion, surface analysis, thermal spray coating, (WC-CO+NiCrBSi), superco-605

1.0 Introduction

While making a choice of substrate material if it is required to select a substrate material with the required design properties that are in contradiction with the properties required for its surface, the coating will be the better option of obtaining desired engineering requirement. The required mechanical strength for the component is obtained by the bulk substrate material, and deposition of coating will help in improving resistance against various degradation factors like erosion, corrosion, oxidation etc., improvements in the surface design properties are made possible by selecting an appropriate coating material, and a process of coating deposition, these selections are made based on the environment in which the component will be used [1].

The components of the turbines will be exposed to a variety of surface degradation processes like hot corrosion, erosion, etc., mining, automotive, aircraft are some of the application areas in which thermal spray coating are being used severely, out of the various available thermal spray coating techniques HVOF process is found to be popular because of the advantages it offers such as low porosity, high bond strength and hardness [2].

The solid particle erosion behaviour of component surface depends on the properties of the base metal or the combination of base metal and the coating composition, and the important factors like operating temperature, angle of impact, particle velocity, properties of the erodent, erodent size and shape [3]. From the literature survey it is clear that coating techniques have proved to be working as resistant to erosion damage, the prime reason for this type of coating is to protect the components from the aggressive environments and intern enhancing the life of the base metal [4].

Prashanth Kumar Singh et al. in their work the coatings of WC-12CO, Stellite 21 and Stellite 6 is deposited on SAE213-T12 boiler steel, coating method used is detonation gun spray method and subjected to solid particle erosion studies. Further it is observed that cobalt content in coating has played a major role on the erosion resistance; Stellite 21 and Stellite 6 coating have shown 50 to 60% higher erosion resistance than WC-Co coatings [5].

Anand Babu K et al. in their work the oxide alloy powder 10%Al_2O_3-CoCrAlTaY is coated on Ti-31 using HVOF spray coating technique and both coated and uncoated samples are subjected to solid particle erosion studies and observed that the rate of erosion is lesser in case of uncoated samples compared to coated ones. In case of HVOF coated samples brittle mode of erosion is observed, and the lesser rate of steady state volumetric erosion of base metal is due to diffusion of erodent particles into the surface of the base metal which help in providing shielding effect against the impacting particles [6]. H.S Sidhu et al. In their study have evaluated erosion behaviour of bare and HVOF spray coated boiler tube steel (GrA1) at 250°C and it was observed that hardness of coating is better than bare steel. In the air jet erosion test shows that higher material loss in coating when compared to uncoated boiler tube steel [7]. Shibe et al. have conducted comparative study of erosion behaviour of three

Messrs. Vinod kumar M S, Assistant Professor, Dr R Suresh, Professor, Department of Mechanical Engineering, Visvesvaraya Technological University Centre for PG Studies, Mysore and Dr. N. Jegadeeswaran, Professor, School of Mechanical Engineering, REVA University, Rukmini Park, Banglore, India. Emal : vinodms@vtu.ac.in / Email: drsureshvtu@gmail.com / njagadeeswaran@reva.edu.in

different types of coating such as WC-12% CO, Cr_3C_2-25% NiCr and Al_2O_3-13% TiO_2 on ASTM36 steel and uncoated ASTM36 steel, and it was observed that all three types of coatings were helpful in protecting base metal from solid particle erosion at 45° impact angle and WC-12% CO, Cr_3C_2-25% NiCr coating were useful in protecting substrate at 60° and 90° impact angles [8]. SB Mishra et al. in their study used three types of coatings such as NiCrAlY, Ni-20Cr and Ni_3Al on nickel based superalloy and subjected to solid particle erosion test and the results show that the coating of Ni_3Al was showing lowest rate of erosion for 30° and 90° angle of impact. The Ni-20Cr coating has shown the highest erosion rate [9]. Mayank Patel et al. have conducted solid particle erosion studies of boiler tube steel SS304 at room temperature, erodent used is being alumina of size 50µm, impact velocity of 40m/sec and impact angle maintained is 30° and 90°, and results show that there is a higher erosion rate at 30° angle of impact compared to 90°, which is indicative of ductile mode of erosion [10]. Mustafa Kaplan et al. have investigated the erosion behaviour of Inconel718 superalloy, two types of coating used are CoNiCrAlY and ZrO_2+8% Y_2O_3 after the air jet erosion test; it was observed that there was a highest erosion rate at 60° impact angle which is indicative of semi ductile/semi brittle mode of erosion [11]. T Aravind Nagaraj et al. have conducted solid particle erosion studies on nickel based superalloy CY5SnBiM for particle velocity of 59, 92 and 124 m/sec and at four different angle of impact namely 30°, 45°, 60°and 90°; test results show that the mode of erosion is ductile and at higher angle of impact it is observed formation of deep pits and craters due to rebounding erodent particles [12].

In the present work the tungsten carbide alloy powder is coated on the base metal Superco-605 using HVOF spray coating technique, the deposited coatings are characterized and evaluated under solid particle erosion test at room temperature as per ASTM G76 standards.

2.0 Experimental work

2.1 Substrate material

Cobalt based super alloy (Superco-605) is the substrate materials used in this study which finds its application in turbine blade and is procured by Midhani Ltd, Hyderabad, India. Details of chemical composition of the base metal as provided by the supplier is shown in Table 1, the material supplied was in sheet form and is cut into the square blocks of size 25mm×25mm×5mm which is further processed for deposition of coating using HVOF thermal spray coating technique.

2.2 Composite coating powder

Table 2 gives the composition details of the alloy powder as provided by the supplier which is deposited on the substrate material Superco-605 using HVOF spray coating technique

Table 1: Substrate material details

Substrate	Chemical composition (%)						
	Cr	Ni	Fe	C	Mn	Si	Co
Superco-605	20	10	3	0.08	1.5	0.3	bal
Application	Furnace equipment, gas turbine components						

Table 2: Details of the alloy powder deposited on substrate material

	coating powder	Composition	shape	Particle size
1	Tungsten Carbide alloy powder	30%WC-Co+70%NiCrBSi (Mechanical blend) Sulzer Metco (Japan) Ltd; Japan	Irregular	-45 to +15µm

Table 3: parameters of spray coating process using HVOF method

Parameter	Details
Rate of flow of fuel in Lpm	60-70
Flow rate of oxygen in Lpm	250
Flow rate of air in Lpm	700
Feed rate of alloy powder in gm/min	0.3-0.5
Spray distance in m	0.2-0.25
Nitrogen pressure in N/m2	49×10^4
Pressure of oxygen in N/m2	98×10^4
Pressure of fuel in N/m2	68×10^4
Pressure of air in N/m2	54 10^4

2.3 HVOF sprays coating

HVOF thermal spray coating is achieved using equipment METCO make model DJ2600, the equipment generates a supersonic jet by burning of fuel (LPG) and oxygen. The process parameters maintained during HVOF spray coating is as shown in Table 3. Prior to HVOF spraying, the substrate material is grit blasted with alumina to obtain improved adhesion between the base metal and the coating. HVOF spray coating is executed at Spraymet coating Industries, Bengaluru, India.

2.4 Erosion test procedure as per ASTM G76 standard

Solid particle erosion test is performed at National Institute of Engineering, Mysuru, India using air jet erosion test rig as per ASTM G76 standard. The room temperature erosion studies were conducted on bare and spray coated samples which will be useful in making a comparative study. Table 2 shows conditions maintained while performing erosion test are listed, initially the candidate metal piece is cleaned with acetone solution to remove any dirt particles; further it is dried and then weighed with the help of electronic weigh balance having accuracy of 0.01 mg. the cleaned sample is fixed on the sample holder of the air jet erosion test rig and then it is subjected to erosion for a period of 5 minutes with the preset test conditions as shown in the Table 4, after the cycle completes the sample is withdrawn from the holder

TABLE 4: PARAMETERS SELECTED FOR CONDUCTING SOLID PARTICLE EROSION TEST

Parameters	Details
Erodent used	Silica sand particles
feed rate of erodent in (g/min)	5
Silica sand particles size in (µm)	150
Temperature in degree celcius	25
Cycle time in minutes	5
Impingement angle in degrees	30, 60, 90
Sample size in mm	25×25×5
Diameter of the nozzle in mm	4.5
Standoff distance in cm	1
Particle velocity in m/s	40

and cleaned and again it is weighed to estimate the erosion rate, which is the ratio of cumulative weight loss of the sample to the weight of the erodent in (gm/gm), and the procedure is repeated until the incremental erosion rate reaches a constant value, further steady state volume erosion rate can be estimated.

3.0 Results and discussion

3.1 COATING POWDER DESCRIPTION

Scanning electron microscopy is used to get the morphology of the coating powder which is depicted in Fig.1. From the figure it is evident that the (30%WC-CO+NiCrBSi70%) powder particles exhibit spherical morphology. The actual size distribution of the coating powder is in the range of -45 to +15µm which is provided by the supplier. And from SEM with EDAX of coating powder it is evident that there is a higher percentage of Ni and lower percentage of B in the coating powder composition

3.2 COATING STRUCTURE EVALUATION

Scanning electron micrographs indicating surface morphologies on the surface of coated samples which is as shown in the Fig.2 and EDAX analysis on the surface of sprayed (30%WC-CO+NiCrBSi 70%) coating as indicates that there is major amount of Ni and minor amount of B.

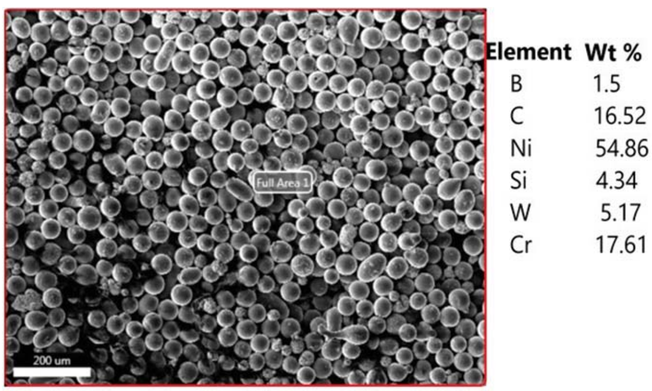


Fig.1: SEM with EDAX of alloy powder

3.3 EROSION RATE AS A FUNCTION OF IMPACT ANGLE: UNCOATED SUPERCO-605

The solid particle erosion test is carried out for three trials and error is estimated to be in the range of 3 to 5%, the erosion scar developed on bare Superco-605 superalloy samples at three different impact angle is as shown in Fig.3, middle part of the erosion mark indicates concentrated zone of material erosion which is encircled by the zone that is exposed to elastic loading, rate of steady state volumetric erosion and erosion rate are determined and Plots of it are as shown in the Figs.4 and 5 respectively, and from the figures it can be observed that there is increased erosion rate and steady state volumetric erosion rate for 90° angle of impact and is at reduced levels at 30° angle of impact which indicates that the mode of erosion is brittle in nature and there is material removal in the form of ploughing and groove formation.

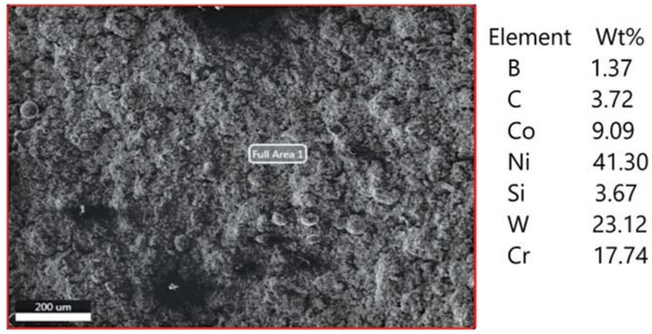


Fig.2: SEM with EDAX of (30%WC-CO+NiCrBSi 70%) coated Superco-605

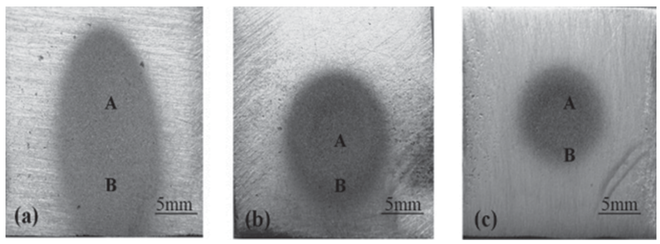


Fig.3: Images of erosion scar on bare Superco-605 at three different impingement angles (a) 30° (b) 60° and (c) 90°

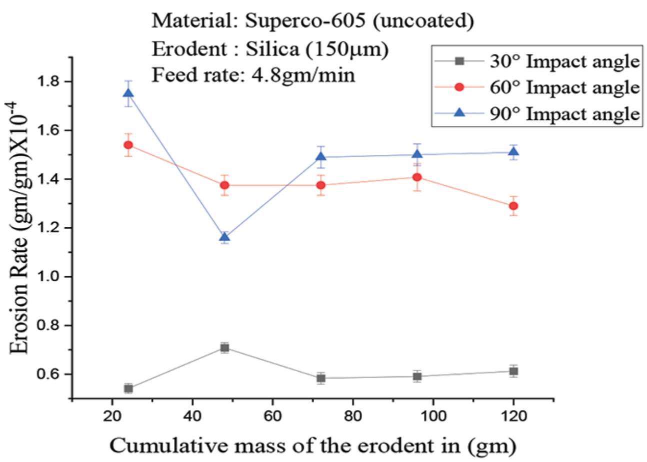


Fig.4: Plot of the erosion rate v/s accruing mass of the erodent

3.4 Solid particle erosion of (30%WC-CO+70% NiCrBSi) coated superalloy Superco-605

The scar mark obtained due to erosion on (30%WC-CO+NiCrBSi 70%) coated Superco-605 sample at 30°, 60° and 90° angle of impact is shown in Fig.6, mid part of scar developed indicates the area which is subjected to extensive erosion and there is a region which surround the central portion of the scar which is exposed to elastic loading. Erosion rate and rate of steady state volumetric erosion are determined and Plots of it are as shown in the Figs.7 and 8 respectively. From the figures it is indicated that erosion rate is higher at 90° angle of impact and lesser at 30° angle of impact. And alike behaviour can be observed in steady state volumetric erosion rate also, which is the characteristic behaviour of brittle material.

Fig.9a shows the SEM with EDAX of erosion scar developed at 30°, 60° and 90° angle of impact on (30%WC-CO+NiCrBSi 70%) coated Superco-605 superalloy sample, from the images it can be observed that material removal is happening due to crater and crack formation and impingement of erodent silica, usually erodent which is of sub millimetre size and angular in shape, erosion is going to happen by lateral cracking due to repeated hitting of solid erodent particles cross cracks are developed, consequently

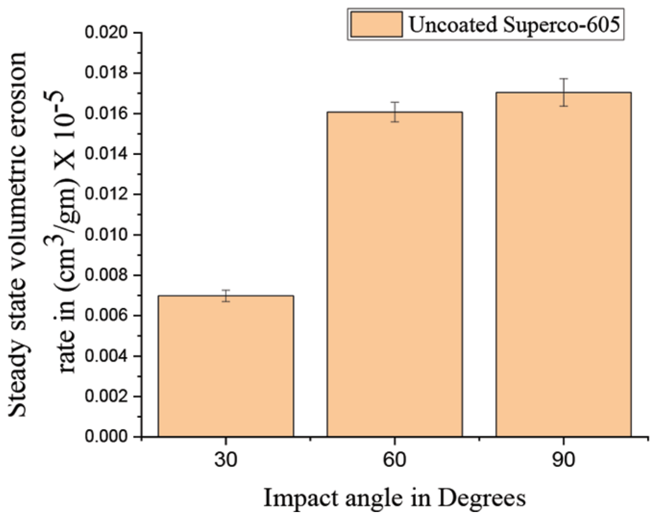


Fig.5: plot of steady state volumetric erosion rate for different impact angle

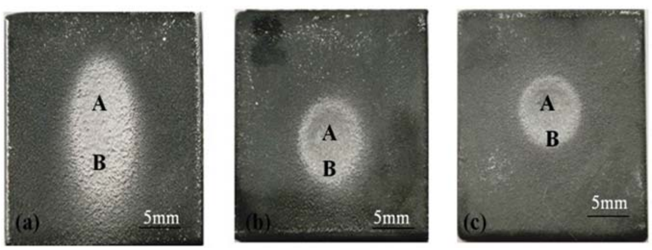


Fig.6: Erosion scars developed on (30%WC-CO+NiCrBSi 70%) coated Superco-605 sample at three different angle of impingement (a) 30° (b) 60°, and (c) 90°

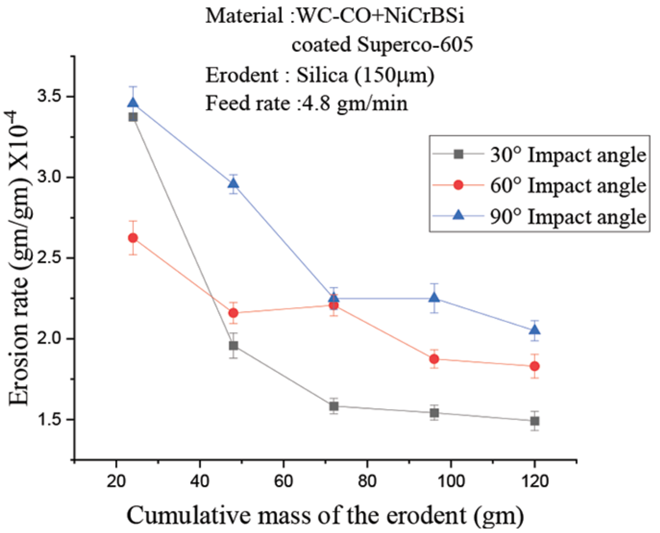


Fig.7: Plot of the erosion rate vs accruing mass of the erodent

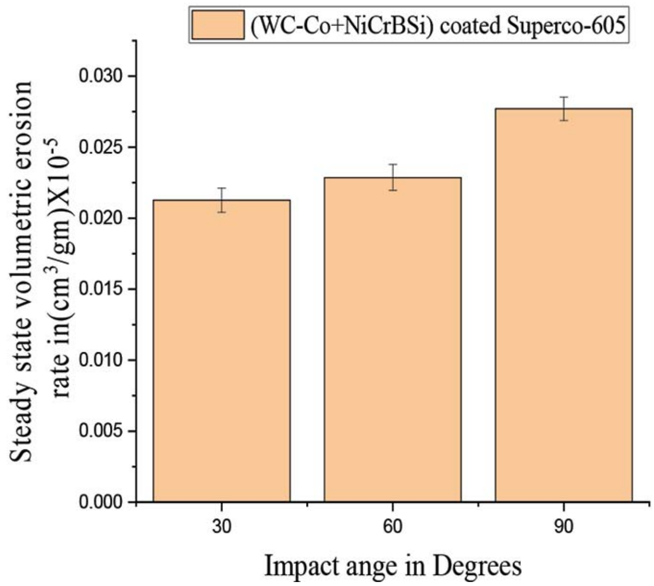
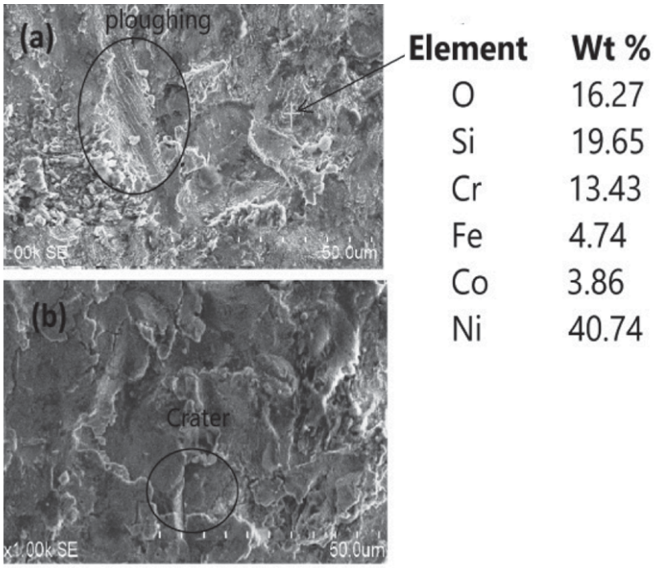


Fig.8: steady state volumetric erosion rate for different impact angels

they have loosen the portion of the material which would fall off in the subsequent impact of erodent particles.

From SEM micro graphs of eroded samples it is observed that formation of crater is severe. Coarse and semi molten splats are spattered into pieces due to impact of solid particles, and the cracks which are developed due to breakup got associated and resulted in fall of from the bulk of the coating, and in this course of action small craters have got created; in some of the regions, it is observed that complete hard faces have separated. This will happen in a location where there is poor interface, which will happen because of semi melting of the powders in HVOF spray coating process, because of impact of very hard particles on the soft phase of the alloy powder coating the soft matrix phase will be exposed to plastic deformation.



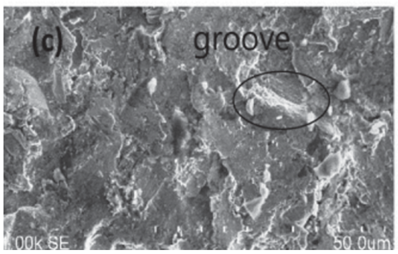


Fig.9: SEM with EDAX of Eroded (30%WC-CO+NiCrBSi70%) coated Superco-605 superalloy at (a) 30°, (b) 60° (c) 90° impact angle

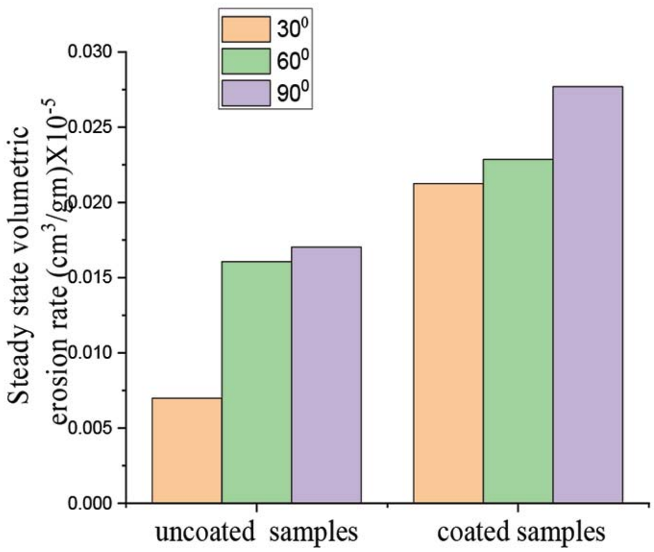


Fig.10 comparison of plots of steady state volumetric erosion rate of coated and bares samples

Fig.10 gives the evaluation of steady state volumetric erosion rate for bare Superco-605 and (30%WC-CO +NiCrBSi 70%) spray deposited samples eroded at 30^0, 60^0 and 90^0 angle of impact, on comparison it is clear that there is a elevated erosion loss of material in case of coated samples as that of bare sample, the increased erosion rate in case of coated samples is indicative that mode of erosion is brittle and lower erosion in uncoated sample is due to penetration of erodent in to the substrate material and helps in providing a shielding effect against further erodent particles which results in low material loss due to erosion.

4.0 Conclusions

1. Deposition of composite 30%WC-CO+70%NiCrBSi coating on Superco-605 superalloy is successful using HVOF process with LPG as the fuel.
2. WC-CO+NiCrBSi coating shows withholding of higher amount of Ni in the matrix with a slight amount of B which justifies the negligible decomposition of the coating powder due to selected parameter during HVOF spraying.
3. Mainly brittle mode of erosion is observed in 30%WC-CO+70%NiCrBSi coated Superco-605 superalloy, the surface morphology indicates the formation of crates and grooves.
4. Uncoated Superco-605 superalloy exhibit low erosion rate as compared to 30%WC-CO+70%NiCrBSi coated Superco-605 superalloy under alike test conditions, due to penetration of solid particles of the erodent on the surface would provide a protecting effect against successive impacting erodent particles and erosion which would generally occur because of indentation induced plastic deformation.

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