# Solid Particle Erosion Performance of Multi-layered Carbide Coatings (WC-SiC-Cr_3C_2)

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# Solid Particle Erosion Performance of Multi-layered Carbide Coatings ($WC$-$SiC$-$Cr_3C_2$)

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**Abstract**: A modern machine parts such as gas turbine blades and vanes are impacted by high temperature and high speed solid dust particles. As a result may leads to disastrous failure. In order to increase the performance multilayered ($WC$-$SiC$-$Cr_3C_2$) carbide coating was developed on AISI 304 steel using HVOF process. Erosion test as per ASTM G 76 standard were conducted at differently impingement angle ($90^0$,$75^0$,$60^0$,$45^0$ and $30^0$) at room temperature. Micro structural, morphological and element analysis probed using SEM and EDAX. The changes in the resistance to erosion are due to high hardness and less porosity of the developed coating. The analysis showed a well-adhered and dense layer with a uniform distribution and presence of carbides and ability to withstand the erosive effects of solid dust particles.

Keywords: Multi-Layer, Coating, Solid particle, Turbine Erosion.

## 1. Introduction

Due to solid particle erosion at high pressure and temperature, the gas turbine blades deteriorated[1-3]. Hence, improving the resistance for the blades erosion could extend the working life. As an efficient and economic technology, coatings are designed to provide protective measures on the blades surface[4]. The thermal spray coating is considered as efficient and economic technique to provide protective measures on the surface of the blades[5]. To resolve the erosion issue, extensive studies have been conducted on factor that influences the erosion and mechanism of erosion[6]. Though, no researchers and scientists could forecast all circumstances of erosion and still it is a big challenge in surface engineering[7-10]. Due to the superior hardness, less porosity, good toughness and good resistance to erosion these WC, Cr Sic powder particles were used[11]. Hard WC provides high hardness and usage of Cr particles shows good toughness[12-15]. In previous paper, we have studied the solid particle erosion behaviour of multi-layered $WC$-$Sic$-$Cr_3C_2$ coated steel at different impingement time at room temperature. It was confirmed that, erosion rate was increases with increasing the impingement time[16].

In an analysis of the erosion wear behaviour of coatings made of WC-12Co and WC-10Co-4Cr that were applied using HVOF thermal spraying, the WC- 10Co-4Cr coating demonstrated greater erosive wear resistance than the WC- 12Co coating under test conditions and displayed good microstructural characterization, erosion resistance rate and thickness residual stresses of the coatings[17]. Two different plasma spray coating systems were created, a microstructural analysis was done, mechanical properties were established and solid particle erosion was identified. An experiment revealed that the coatings had good density, adhesive strength, and hardness, and that volume erosion was more noticeable at 45° angle of impact[18]. Solid particle erosion resistance is increased by the existence of a ductile crystalline, fine carbide precipitates and embedded erodent particles[19]. The lower layer thickness displayed superior erosion resistance in resemblance to those with higher layer thickness[20]. According to laboratory particle erosion tests, the coated structure's lifetime has increased by up to four times compared to its uncoated equivalent[21]. The efficiency of the existing high velocity air fuel (HVAF) system for scattering tungsten carbide (WC-10Co4Cr) and chromium carbide based hard metal coatings spray method operated by gaseous state and liquid operated high velocity oxygen fuel (HVOF) spray method is compared. The HVAF sprayed coatings sustained impact resistance that had been nearly as high as the WC-10Co sintered material [22-23].

In this manuscript, we present the deposition of multilayered coating of $Wc$-$SiC$-$Cr_3C_2$ on AISI 304 steel at thickness of 150 micrometer using HVOF process. Numbers of impingement angles were varied to analyses the erosion behaviour of samples with and without coatings. Microstructure and morphological studies were conducted by using scanning electron microscope & EDAX. These coatings are useful for protecting surfaces against erosion by solid particles because they combine hardness, toughness, and thermal stability. Understanding the erosion behavior of multilayered carbide coatings is essential for optimizing their performance and expanding their practical applications where erosion is a critical concern.

## 2. Experimental Details

### 2.1 Substrate material

The AISI 304 stainless steel was received from reputed steel supplier in Bangalore. Due to good mechanical properties, this steel was chosen as the primary substrate material. The steel chemical composition is given in Table 1.

Table 1. Composition of AISI 304 steel.

| Element | C | Cr | Mn | Ni | P | S | Si | Fe |
|---|---|---|---|---|---|---|---|---|
| Wt% | 0.07 | 19-20 | 2.01 | 8-11 | 0.046 | 0.03 | 1.1 | Balance |

### 2.2 Coating materials and deposition

Commercially existing tungsten carbide (WC), silicon carbide (Sic) and Chromium carbide ($Cr_3C_2$) metallic powders of nominal particle size of 45 µm were recognized as feedstock particles. Fig. 1 illustrates the particle morphology of the powder. The sharp-edged irregular morphology gives excellent fluidity and stability in the time of deposition[24-26]. Wc-Sic-$Cr_3C_2$ multilayer coating was deposited on bare 304 steel plate of size 35x25x4mm utilizing high velocity oxy fuel (HVOF) deposition system with industrial standard parameters. Before spraying, substrates were degreasing using acetone and grit blasted. The Fig. 2 shows the deposition thickness of 250±30µm.

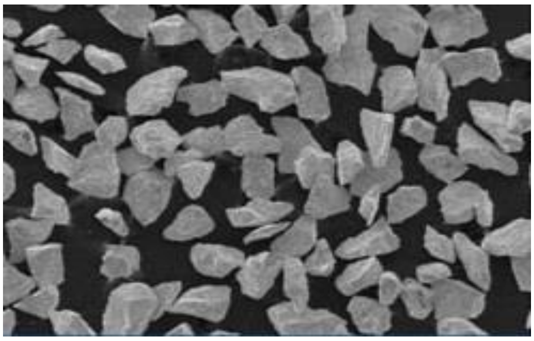

**Fig. 1:** Composite carbide powder particles.

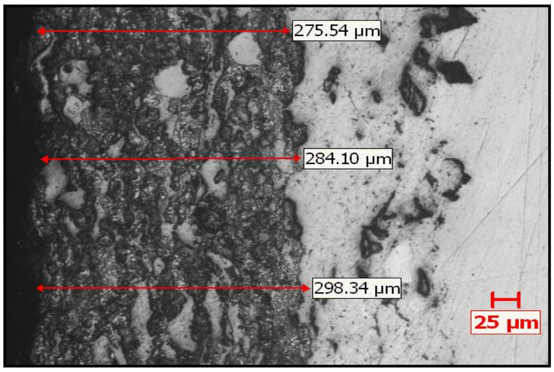


**Fig. 2:** Coating Thickness of 250±30µm.

### 2.3 Characterization method of the coating

The measurement of surface roughness and porosity of coated and uncoated samples was carried out by employing a 3D laser scanning microscope[27-30]. Additionally, the hardness of the interface between the coated and uncoated samples was assessed using a Vickers micro hardness tester. This testing method allowed for a precise measurement of the resistance to deformation and the hardness of the material at a microscopic level. By analyzing the hardness of the interface, it was possible to determine the effectiveness of the coating in terms of enhancing the mechanical properties of the substrate

### 2.4 Testing for erosion

By following ASTM G76 standard, solid particle erosion test was conducted at room temperature by using 312 µm sized silica sand particles. The solid sand particles were loaded into a hopper which is in top of the test rig and introduced into high pressure gas stream. The stream passes through the nozzle which is made from silicon carbide and particles are directed towards the fixed substrates in sample holder of the test rig with high velocity at a present impingement angle ($90^0$ to $30^0$). During testing, the nozzle tip distance to specimen and time of impingement were kept constant. A precision balancer with accuracy of 0.0001 was used to determine how quickly the coated and uncoated specimens eroded.

## 3. Analysis of microphotograph and coatings of the mechanical properties

The SEM was used to analyze the surface morphology of the multilayer coated samples (before erosion experiment) as shown in Fig. 3. Micro photograph confirms the uniform distribution of the coated particles. EDAX spectrum technique was used to confirm the composition of the coated particles. EDAX spectra were showed in Fig.4 the coating thickness was measured between the interface of the coating and base substrate and it was achieved as 250±30 µm.


**Fig. 3:** SEM microphotograph of Composited coated sample.

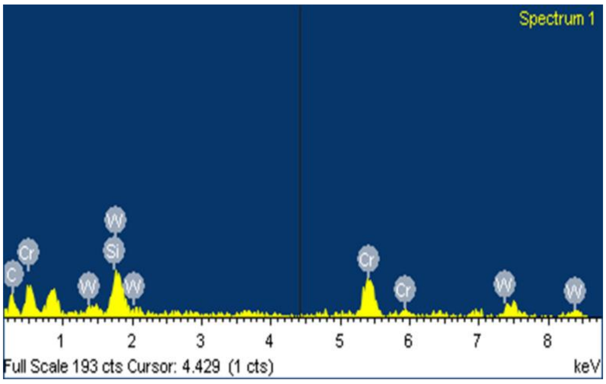


**Fig. 4:** EDAX Spectrum Analysis of the coated sample.

Using the ASTM E-384 standard, the regular surface hardness of with and without coated samples was determined. The hardness values of the both with and without coating samples were shown in Fig. 5. From the results it has been confirmed that, excellent adhesion was obtained due to high surface roughness of the base substrate due to grit blasting and it leads to avoid the delaminating of the coatings from the substrate upon impingement of solid silica particles.

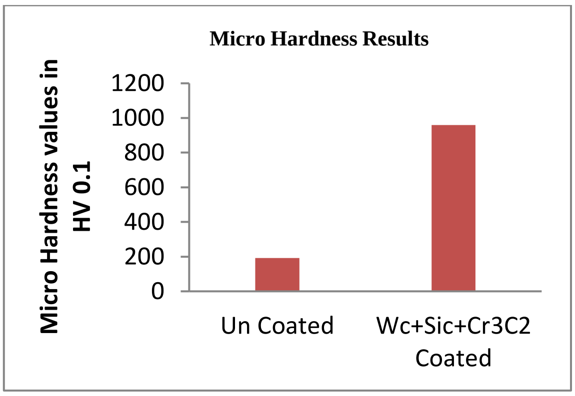


**Fig. 5:** Micro hardness Values of the coated and uncoated samples.

Erosion rate in mass of the bare 304 steel and multilayer coated and un coated samples are presented in Fig. 6. And it has been confirmed that, multilayered Wc-Sic-$Cr_3C_2$ coatings shows improvement in erosion resistance compared to 304 steel that is uncoated.

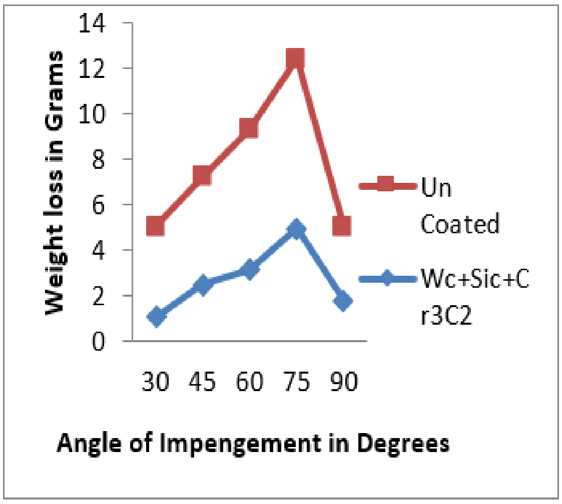


**Fig. 6:** Erosion rate of multi-layer coated and un coated Samples at different impingement angles.

The solid particle eroded surfaces of the multilayered coated and uncoated samples were observed under SEM and are presented in Fig. 7(a-b-c) and Fig. 8(a-b-c). From the Fig. 8 (a) – Fig. 8 (c) coated substrates shows a representative plate like lamellar structure along with micro crack, voids. Fig. 7 and Fig. 8 show the increasing in weight loss of samples at different impingement angles. At $30^0$ impact angles increasing in weight loss occurs in uncoated samples which were lower as compared to $60^0$ and $90^0$ the kinetic energy of solid particles increases and more effective than other angles and this leads to formation of grooves and lips in uncoated samples than the coated samples. The silica particles cause breaking ground and micro cutting on the uncoated samples at all impingement angles[31-33]. At high impact angle $90^0$ the multilayer coated samples surface was removed by forming the small cracks. At high impact angle, due to less contact area as compared to $30^0$ less fracture has happened on both coated and un coated samples. According to the explanation above, multilayer coating is a crucial factor in improving the solid particle erosion behaviour of AISI 304 stain-free steel, in addition to the coated sample mechanical qualities[34-39].

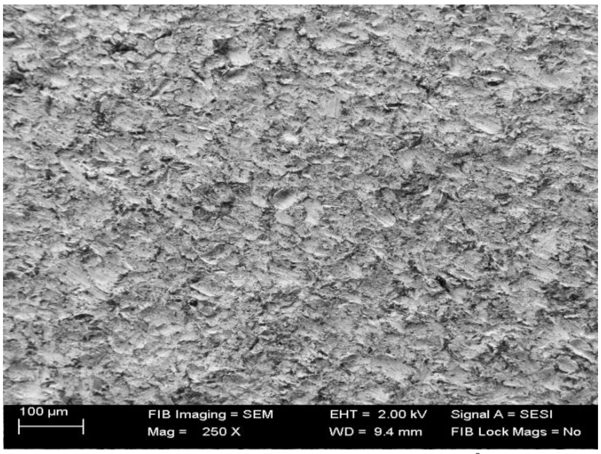


**Fig. 7(a):** Un coated samples at 30$^0$.

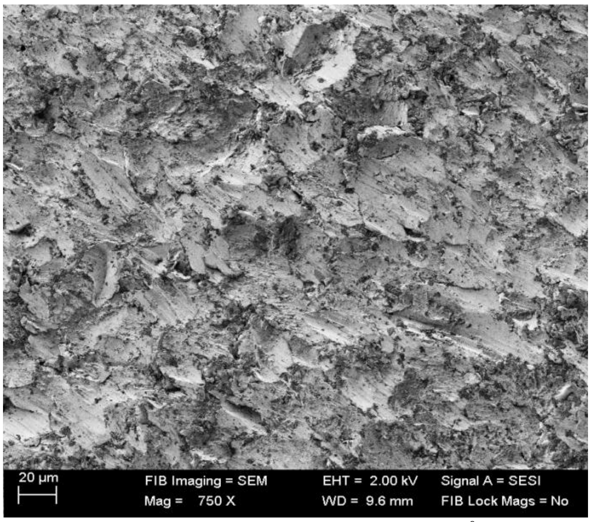


**Fig. 7(b):** Un coated samples at 60$^0$.

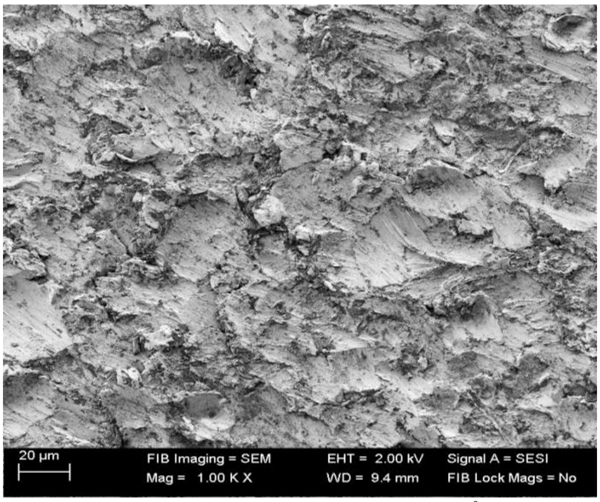


**Fig. 7(c):** Un coated samples at 90$^0$.

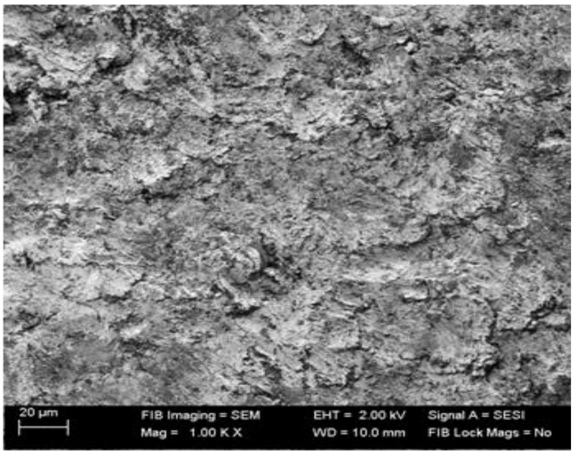


**Fig. 8(a):** Coated samples at 30$^0$.

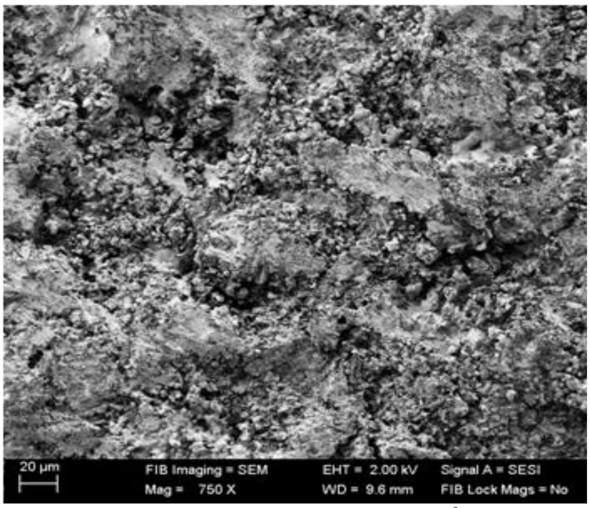


**Fig. 8(b):** Coated samples at 60$^0$.

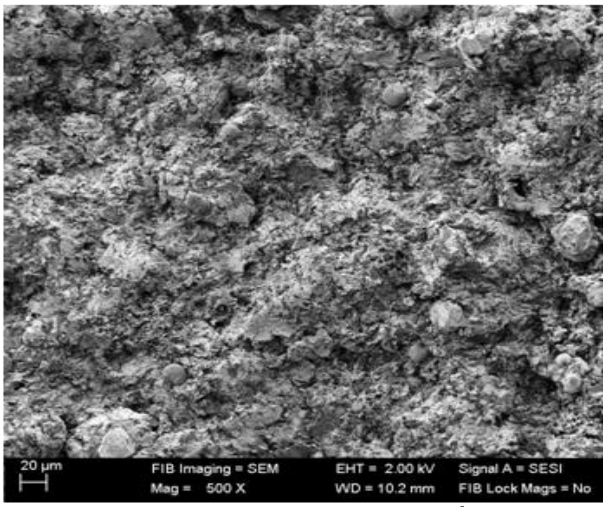


**Fig. 8(c):** Coated samples at 90$^0$.

## 4. Conclusion

When subjected to solid particle erosion at various impingement angles, the studied multi-layered coatings demonstrated evidence of withstanding plastic deformation. The multi-layered coatings that were developed are an excellent alternative for enhancing the erosion resistance of components, especially those used in turbine blade materials. The solid particle erosion resistance of the developed coatings increases as the impingement angle is increased up to 75$^0$, but at 90$^0$ there is a decrease in erosion resistance due to less impact from the particles. The multi-layered coating with a thickness of 250µm showed greater resistance to solid particle erosion at different impingement angles. The study demonstrated that multilayered carbide coatings composed of WC, SiC, and $Cr_3C_2$ exhibit good erosion resistance. The findings of these studies provide important insights into the design and optimization of multilayered carbide coatings.

## References


1) K.V.Sreenivas Rao, Girisha K.G, Sushruta Eswar, "Effect of Erodent Impact Angle on the Erosion Behaviour of Plasma Sprayed Cr2O3 coating on Martensitic steel," *Materials Today: Proceedings,* **4**, 10221–10224, (2017). doi.org/10.1016/j.matpr.2017.06.352
2) M.R. Ramesh, S. Prakash, S.K. Nath, Pawan Kumar Sapra , B. Venkataraman , "Solid particle erosion of HVOF sprayed WC-Co/NiCrFeSiB coatings," *Wear*, **269**, 197–205, (2010). doi.org/10.1016/j.wear.2010.03.019
3) D. Tejero-Martin, M.Rezvani, McDonald, T. Hussian "Beyond Traditional Coatings: A Review on Thermal-Sprayed Functional and Smart Coatings," *Journal of Thermal Spray Technology,* **28**, 598–644, (2019). doi.org/10.1007/s11666-019-00857-1
4) K.V. Sreenivas Ra ,Girisha K G , Jamuna K , Tejaswini G, Erosion, "Behaviour of HVOF Sprayed SiC-WC-Cr3C2 Multilayer Coating on 304 Stainless Steel," *Materials Today: Proceedings,* **5**, 24685–24690, (2018). doi.org/10.1016/j.matpr.2018.10.266
5) Priit Kulu, Irina Hussainova, Renno Veinthal, "Solid particle erosion of thermal sprayed coatings," *Wear*, **258**, 488–496, (2005). doi.org/10.1016/j.wear.2004.03.021
6) J.K.N. Murthy, D.S. Rao, B. Venkataraman, "Effect of grinding on the erosion behavior of a WC–Co–Cr coating deposited by HVOF and detonation gun spray processes," *Wear*, **249**, 592–600, (2001). doi.org/10.1016/S0043-1648(01)00682-2
7) Hui Wang, W. Xia, Yuansheng Jin, "A study on abrasive resistance of Ni-based coatings with a WC hard phase," *Wear*, **195**, 47–52, (1996). doi.org/10.1016/0043-1648(95)06762-0
8) Jianhui Yuan, Chunwei Ma, Shanglei Yang, Zhishui Yu, Hua Li, "Improving the wear resistance of HVOF sprayed WC-CO coatings by adding submicron-sized WC particles at the splat's interfaces," *Surface and coating technology*, **285**, 17-23, (2016). doi.org/10.1016/j.surfcoat.2015.11.017
9) Gursharan Singh, Sukhinderpal Singh and Jasmaninder Singh Grewal, "Erosion wear characterisation of DLC and AlCrN-based coated AISI-304/316 steels," *Surface engineering*, **35**, 304-316,(2019). doi.org/10.1080/02670844.2018.1478685
10) Warjito, Oimolala Putrawan, Budiarso, Ridho Irwansyah, Sanjaya BS Nasution, "The Numerical Study of the Effect of Blade Depth and Rotor-Basin Ratio on Vortex Hydro Turbine Performance", *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **09**(02), 556-562, (2022), doi.org/10.5109/4794187
11) Subhrajit Ray, "Effect of Control Parameters on Erosion Wear Performance of Glass-Epoxy Composites Filled with Waste Marble Powder" *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **09** (01), 23-31, (2022), doi.org/10.5109/4774213
12) Hudzaifah Al Hijri, Jaka Fajar Fatriansyah, Nofrijon Sofyan, Donanta Dhaneswara, "Potential Use of Corn Cob Waste as the Base Material of Silica Thin Films for Anti-Reflective Coatings" *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **09**(01), 102-108, (2022), doi.org/10.5109/4774221
13) Anil K C, Kumaraswamy, Mahadeva Reddy, Mamatha K M, "Air Jet Erosion studies on Aluminum - Red Mud Composites using Taguchi Design." *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **10**(01), 130-138, (2023). doi.org/10.5109/6781059
14) Tom Peat, Alexander Galloway, Athanasios Toumpis, David Harvey, Wei-Hua Yang, "Performance evaluation of HVOF deposited cermet coatings under dry and slurry erosion," *Surface and coating technology*, **300**, 118-127, (2016). doi.org/10.1016/j.surfcoat.2016.05.039
15) Avnish Kumar, Ashok Sharm, S.K. Goel, "Erosion behaviour of WC-10Co-4Cr coating on 23-8-N nitronic steel by HVOF thermal spraying," *Applied surface science*, **370**, 418-426, (2016). doi.org/10.1016/j.apsusc.2016.02.163
16) Y. Y. Santana, J. G. La Barbera-Sosa, A. Bencomo, J. Lesage, D. Chicot, E. Bemporad, E. S. Puchi-Cabrera, and M. H. Staia, "Influence of mechanical properties of tungsten carbide–cobalt thermal spray coatings on their solid particle erosion behaviour", *surface engineering*, **28**, 237-243, (2012). doi.org/10.1179/1743294411Y.0000000016
17) Digvijay G. Bhosale, T. Ram Prabhu, Walmik S. Rathod, "Sliding and erosion wear behaviour of thermal sprayed WC-$Cr_3C_2$-Ni coatings," *Surface and coating technology*, **400**, 126-192, (2020). doi.org/10.1016/j.surfcoat.2020.126192
18) N. Krishnamurthy, M. S. Murali, B. Venkataraman, P. G. Mukunda, "Characterization and solid particle erosion behavior of plasma sprayed alumina and calcia-stabilized zirconia coatings on Al-6061 substrate", *Wear*, **274-275**, 15-27, (2012). doi.org/10.1016/j.wear.2011.08.003
19) J.K.N. Murthy, K. Satya Prasad, K. Gopinath, B. Venkataraman, "Characterisation of HVOF sprayed

Cr3C2-50(Ni20Cr) coating and the influence of binder properties on solid particle erosion behaviour", *Surface and coating technology*, **204**, 3975-3985, (2010). doi.org/10.1016/j.surfcoat.2010.04.069

20) Venkataramana Bonu, M. Jeevitha, Praveen Kumar V., Harish C. Barshilia, "Nanolayered multilayer Ti/TiN coatings: Role of bi-layer thickness and annealing on solid particle erosion behaviour at elevated temperature", *Surface and coating technology*, **357**, 204-211, (2019). dx.doi.org/10.1016/j.surfcoat.2018.10.007
21) Daniel Eichner, Antje Schlietera, Christoph Leyens, Lin Shang, Seyedmohammad Shayestehaminzadeh, Jochen M. Schneider, "Solid particle erosion behavior of nanolaminated Cr2AlC films", *wear*, **402-403**, 187-195, (2018). doi.org/10.1016/j.wear.2018.02.014
22) V. Matikainena , S. Rubio Peregrinaa , N. Ojalaa , H. Koivuluotoa , J. Schubertb , Š. Houdkováb , P. Vuoristoa, "Erosion wear performance of WC-10Co4Cr and Cr3C2-25NiCr coatings sprayed with high-velocity thermal spray processes", *surface and coating technology*, **370**, 196-212, (2019). doi.org/10.1016/j.surfcoat.2019.04.067
23) Mithlesh Sharma, Deepak Kumar Goyal, Gagandeep Kaushal, "Tribological investigation of HVOF sprayed coated turbine steel under varied operating conditions," *Materials today proceedings*, **24**, 869-879, (2020). doi.org/10.1016/j.matpr.2020.04.397
24) Girisha K G, Anil K C, Akash, K. V, Sreenivas Rao, "Investigation of HVOF Thermal Sprayed Micro B4C, Micro-1%, 2%, 3% Nano B4C Coatings on Dry Sliding Wear Performance of 410 Grade Steel", *ARPN Journal of Engineering and Applied Sciences*, **11**, N0.1, (2016).
25) K. V. Sreenivas Rao, Girisha K. G., and Anil K. C., Akash, " Dry Sliding Wear Performance Of Thermal Sprayed Micro-Nano Boron Carbide Coating On 410 Grade Steel", *ARPN Journal of Engineering and Applied Sciences*, **11,** No.6, (2016).
26) Girisha K G, Anil K C, Akash**,** K V Sreenivas Rao, "Dry Sliding Wear behaviour of B4C Coating on AISI 410 Stainless Steel Deposited by HVOF Spraying", *International Journal of Applied Engineering Research,* **10**(11), 10270-10275, (2015).
27) S. Silviana, Angga Gata Hasega, Aulia Rizqy Nur Hanifah, Afriza Ni'matus Sa'adah "Synthesis of Silica Coating Derived from Geothermal Solid Waste Modified with 3-Aminopropyl Triethoxysilane (APTES) and Silver Nano Particles (AgNPs)" *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **09**(04), 1224-1230, (2022), doi.org/10.5109/6625733
28) Anthony Chukwunonso Opia1, Mohd Kameil Abdul Hamid, Samion Syahrullail, Audu brahim Ali1, Charles N. Johnson, Ibham Veza, Mazali Izhari Izmi, Che Daud Zul Hilmi, Abu Bakar Abd Rahim, " Tribological Behavior of Organic Anti-Wear and Friction Reducing Additive of ZDDP under Sliding Condition: Synergism and Antagonism Effect" *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy,***09**(02), 246-253, (2022), doi.org/10.5109/4793628
29) Hans Juliano, Femiana Gapsari, Hubby Izzuddin Toto Sudiro, Krisna Yuarno Phatama, William Putera Sukmajaya, Zuliantoni1, Thesya Marlia Putri, Abdul M Sulaiman, " HA/ZrO2 Coating on CoCr Alloy Using Flame Thermal Spray" *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, Vol. **09** (02), 254-261, (2022), doi.org/10.5109/4793632
30) Kanwalpreet Sahni and Jasmaninder Singh Grewal, "Slurry erosion behaviour of WC-10Co-4Cr coated CF8M turbine steel," *Materials today proceedings*, **56**, 2666-2671, (2022). doi.org/10.1016/j.matpr.2021.09.236
31) Lalit Thakur, N. Arora, R. Jayaganthan, R. Sood, "An investigation on erosion behaviour of HVOF sprayed WC-CoCr coatings," *Applied surface science*, **258**, 1225-1234, (2011). doi.org/10.1016/j.apsusc.2011.09.079.
32) Xiang Ding, Xu-Dong Cheng, Jin Shi, Chao Li, Cheng-Qing Yuan and Zhang-Xiong Ding, "Influence of WC size and HVOF process on erosion wear performance of WC-10Co4Cr coatings," *The international journal of advanced manufacturing technology*, **96**, 1615-1624, (2017). doi.org/10.1007/s00170-017-0795-y
33) Deepak Kumar Goyal, Harpeet Singh and Harmesh Kumar, "Characterization and accelerated erosion testing of WC-Co-Cr-and C0NiCrAlY-coated CA6NM turbine steel," *Journal of thermal spray technology*, **28**, 1363-1378, (2019). doi.org/10.1007/s11666-019-00897-7
34) Lalit Thakur, N. Arora, "A study of processing and slurry erosion behaviour of multi-walled carbon nanotubes modified HVOF sprayed nano-WC-10Co-4Cr coating," *Surface and coating technology*, **309**, 860-871, (2017). doi.org/10.1016/j.surfcoat.2016.10.073
35) J. Pulsford, S. Kamins, J. Murray, M. Bai, T. Hussain, "Effect of particle and carbide grain sizes on a HVOF WC-Co-Cr coating for the future application on internal surfaces: microstructure and wear," *Journal of thermal spray technology*, **27**, 207-219, (2018). doi.org/10.1007/s11666-017-0669-8
36) Girisha K G, K.V. Sreenivas Rao, Anil.K.C, Sanman.S "Experimental investigation on erosive wear behaviour of plasma spray coated stainless

steel", Materials Science and Engineering, 191 (2017) 012022 DOI:10.1088/1757-899X/191/1/012022

37) Latha Shankar, B. Nagaraj, P. M. Anil, K. C "Optimization of Wear Behaviour of AA8011-Gr Composite using Taguchi Technique" Materials Today: Proceedings, Volume 4, Year 2017, Pages 10739-10745. DOI: 10.1016/j.matpr.2017.08.021

38) Latha Shankar, B.;Anil, K. C.;Patil, Rahul " A Study on 3-Body Abrasive Wear Behaviour of Aluminium 8011 / Graphite Metal Matrix Composite" OP Conference Series: Materials Science and Engineering, Volume 149, Year 2016. DOI:10.1088/1757-899X/149/1/012099.

39) Girisha, K.G., C. Durga Prasad, K.C. Anil, and K.V. Sreenivas Rao. "Dry Sliding Wear Behaviour of $Al_2O_3$ Coatings for AISI 410 Grade Stainless Steel." Applied Mechanics and Materials. Trans Tech Publications, Ltd., June 2015. https://doi.org/10.4028/www.scientific.net/amm.766-767.585