Waterdrop erosion of HVOF and PVD coatings

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Aeronautic industry is concerned by reinforcement of surface to improve erosion resistance. Within this framework, a wide range of coatings have been achieved and tested to identify and verify main erosion mechanisms according to technologies and materials.

In this goal, the erosion resistance of PVD and HVOF coatings on stainless steel substrate has been appraised thanks to water jet pulsated device \cite{1}. The substrates are in all cases 0.9 mm-thick rough-rolled AISI301 stainless steel.

First, stainless steel coatings have been deposited by both PVD and HVOF way to evaluate the influence of the structure of the coatings. HVOF-AISI316L and PVD-AISI304 coatings have be considered here as references.

Then, HVOF WC/CoCr has been studied because of its good resistance reputation. By the other way, PVD allows to achieve a wide sort of coatings. Then, have also been tested metallic gum (CuZr), hard coating (TiCrAlN), and Diamond-Like-Carbon (DLC).

Characterization of coatings

Our study revealed that so-called Mercedes indentation test was not sensitive enough to anticipate the coating failure during water droplet erosion tests. Scratch tests have then been used to characterize coatings because they are supposed to be more sensitive.

As shown by Figure 1, 3 \textmu{}m-thick CuZr coating shows an excellent behaviour during the test. In opposition, 20 \textmu{}m-thick CuZr of same composition presents a lot of perpendicular cracks in the scratch bottom, and finishes in failure.

In the case of DLC, some very little flakes can be observed in the scratch track. TiCrAlN show both cracks and flakes due to brittleness. To finish with PVD coatings, AISI304 samples (both 3 and 10 \textmu{}m-thick) display some perpendicular cracks in the bottom of the line. However, defects in the 10 \textmu{}m-thick sample are more important and results in flakes.

Concerning HVOF samples, roughness has perturbed observations. Nevertheless, both coatings don’t withstand load and rapidly failed in large peeling.
Erosion rate evaluation

First, reference has to be considered. Rough-rolled sample of AISI301 shows regular erosion until 5 million impacts. The topography of HVOF Stainless Steel and PVD CuZr-20µm has not been assessed because these coatings have been widely removed during erosion test.

The topography of erosion damages is shown by the Figure 2. Results of bulk stainless steels are given for comparison. First, topography of WC/CoCr clearly shows that this coating is not as resistant as uncovered sample.

Secondly, concerning PVD coatings, CuZr-3µm, DLC-1µm, AISI304-3µm and TiCrAlN-3µm show similar behaviour. At the beginning, these samples seem to improve the crack initiation stage. After 1 or 2 million impacts, lost volume increases. Their erosion rate seems to be a little lower than the erosion rate of C1000. Among these samples, DLC-1µm seems to be the better one. If we consider the impacts requisite to pull out $20 \times 10^6$ $\mu$m$^3$ of matter, the gain of these coatings ranges from 1 to 1.5 million impacts.

To finish, AISI304-10µm shows particular behaviour. Until 1 million impacts, surface earns volume. This is due to very small blister. At 2 million impacts, the lost volume increases and
becomes important. Finally, this sample shows the weakest behaviour according to loss volume, but it presents the most important incubation duration.

**Surface and transversal observations**

HVOF coatings show erosion vulnerability. First, AISI316L coating has been completely removed due to lack of adhesion. In the case of WC/CoCr, erosion creates progressively a crater. Substrate is visible as soon as 1 million impacts. Cut observations of reference samples reveal a lot of porosities and some cold shuts (Figure 3.a). During erosion tests, cracks grew thanks to these defects (Figure 3.b).

Concerning PVD coatings, behaviours differ. These coatings are so thin that rough-rolled morphology is conserved by the coating. The marks of the grain boundaries clearly result in coating perturbations (see Figure 4).

When coatings show a lack of adhesion, coating failed and revealed substrate surface (see Figure 4). In the case of the most adhesive coatings, substrate interface resists. Nevertheless, then embrittlement is observed resulting in spalling. Cracks are supposed to grow in substrate for the thinnest coating, and in the coating for the thickest. As an example, in the case of AISI304-10µm, coating suffers from embrittlement until breaking into the coating (confirmed by cut observations, see Figure 5). Then facies clearly show fatigue cracks aspect (Figure 6).
Conclusion

After having characterized coatings, Mercedes test has appeared to not be sensitive enough whereas scratch test presents good correlation with erosion tests. In facts, HVOF samples (both Stainless Steel and WC/CoCr), TiCrAlN-3µm and stainless steel 10µm PVD coating show important defects during scratch tests which results from lack of both adhesion and resistance. Moreover, these coatings are the weakest during erosion tests. Finally, our works lead to a correlation between results of erosion tests and scratch tests.

Our tests finally show that on the one hand, HVOF coatings have a very bad erosion resistance due to both lack of adhesion and internal porosities which support cracks growth. On the other hand, PVD coatings finally benefit to initiation time and are able to upgrade service life. Their erosion resistance depends mainly on coatings adhesion. Hence, scratch tests would be considered as an intermediate step to design erosion-resistance solutions.

References