WATER DROPLET IMPINGEMENT EROSION: *TESTING, MECHANISMS AND IMPROVED REPRESENTATION*

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Summary Water Droplet Impingement Erosion (WDIE) is a result of liquid/solid interaction at high speeds (sub/supersonic speeds). Extensive research is carried out at the TMG lab at Concordia University to further understand this phenomenon. It is of great concern to the power generation and aerospace industries and leads to failure of multiple airplanes components, when flying in the rain, steam turbine blades, and gas turbine compressor blades. In this article, WDIE mechanisms of Martensitic 12% Cr stainless steel, TiAl4V and TiAl, widely used alloys in the power generation and aerospace fields, are discussed. In addition, a unified energy intensity method to represent WDIE results is presented.

EXPERIMENTAL PROCEDURE

WDIE experiments were performed using a state of art erosion rig, which was designed based on the ASTM G73 standard. A schematic of WDIE rig is presented in Figure 1-a. In a vacuum chamber, the disk rotates at speeds up to 20,000 rpm, which corresponds to 500 m/s linear impact speed. Liquid/solid impingement parameters including impact speed, impact angle, droplet size, and number of impacting droplets are controlled in this test rig. In addition, different types of nozzles (single-ray, multi-ray and shower-head) can be used, as shown in Figure 1-b and 1-c. In this work, a single-ray nozzle generating 460 µm droplets was used. Moreover, the generated droplets impact the surface of samples at relative speeds of 300 and 350 m/s. It is worthy to note that the generated water droplets were shielded against the turbulence occurring inside the chamber to ensure the straightness of water ray with minimum aerodynamic distortion of the droplets until impacting the rotating sample.

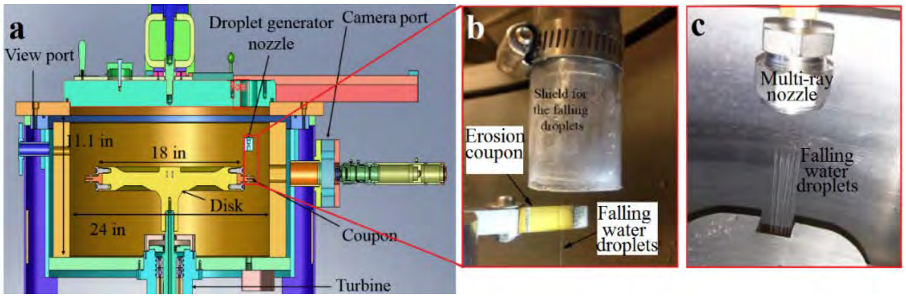

Figure 1. (a) Schematic of water droplet erosion rig, (b) Droplets generated using single-ray nozzle, (c) Droplets generated using multi-ray nozzle.

RESULTS

Erosion performance of structural alloys in aerospace industries

Figure 2 presents the results of a set of experiments performed using a single-ray nozzle for three different alloys: Ti6Al4V, TiAl and 12% Cr stainless steel. In Figure 2-a, the superiority of TiAl could be observed when tested at 300 m/s. As the impact speed increases, TiAl loses its superiority to stainless steel. At 350 m/s, the WDIE performance of the 12% Cr stainless steel becomes superior to both Ti6Al4V and TiAl. It can be concluded that the erosion performance of solid surfaces is a function of many interacting parameters representing the mechanical properties of the solid and the impingement conditions. Figure 2-c shows the evolution of solid damage due to liquid droplet impingements in the case of TiAl.

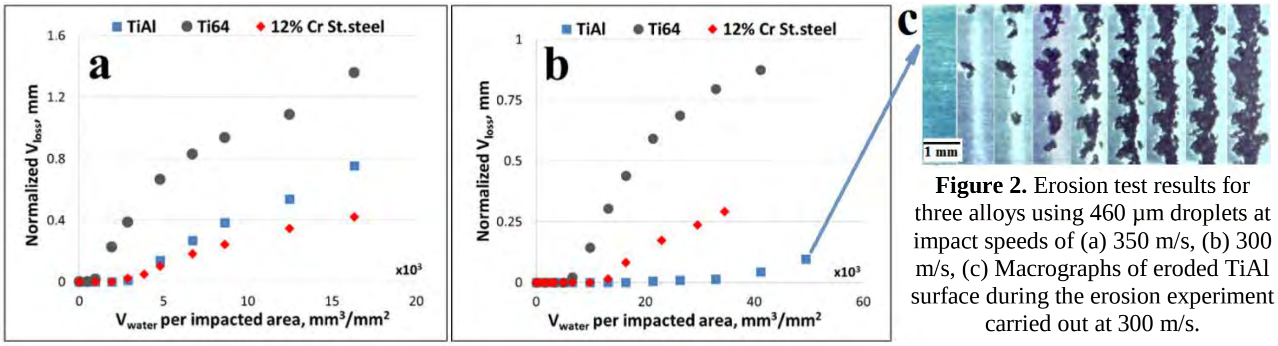

Figure 2. Erosion test results for three alloys using 460 µm droplets at impact speeds of (a) 350 m/s, (b) 300 m/s, (c) Macrographs of eroded TiAl surface during the erosion experiment carried out at 300 m/s.

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Unified energy intensity method

The erosion representation method used in Figures 2-a and 2-b is applicable when comparing the results of WDIE tests carried out using the same experimental procedure, especially when using the same erosion test rig. Different WDIE test rigs have various factors that may influence the erosion results, for instance, the pressure in the rig, the direction of water droplets injection, the amount of water droplets impacting the surface of the sample per cycle, etc. A new method of representation should be developed to directly link the experimental results to the impingement conditions and their physical meanings. If the underlying physical principles are uncovered, experimental results performed using different erosion rigs could be compared accurately, and the differences between test rigs can be accounted for. The physical quantity that could include most of these parameters is the kinetic energy of the impacting water droplets. Therefore, experimental results were re-presented in Figure 3 as curves between the volume loss per unit impacted area and the intensity of the applied kinetic energy. The kinetic energy intensity is calculated using the impingement speed, droplet size and the number of impinging particles. Using kinetic energy intensity as the x-axis is a novel method to represent WDIE test results. The dashed arrow lines in Figure 3-b represent a specific amount of applied kinetic energy, and it is clear that the Ti6Al4V response varies at different test speeds. Understanding the reasons of such variation is the topic of our current and future work. Our most recent findings in this regard will be presented in this conference.

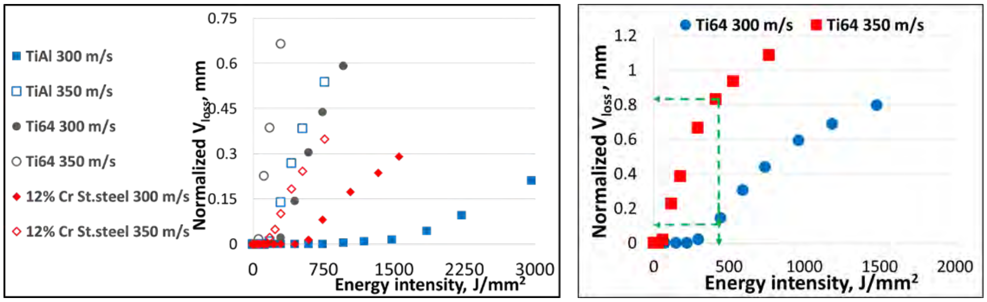

Figure 3. WDIE curves represented using the unified energy intensity method for (a) Ti6Al4V, TiAl and 12%Cr St. Steel, (b) Ti6Al4V.

Erosion damage mechanism

WDIE damage initiation mechanism is a function of erosion severity (liquid/solid interaction conditions) and dynamic mechanical properties of the target. Figure 4 shows a schematic for liquid behaviour and solid response in the case of high speed impingements. Figure 5 demonstrates SEM images of slightly eroded martensitic stainless steel and TiAl alloys within their incubation period. In the case of stainless steel, after initial droplet impacts shallow depressions appeared on the surface, as shown in Figure 5-a. Such depressions led to the generation of surface asperities which became a trigger for material loss initiation. The localized depressions imply that impact pressure of hitting droplets would be higher than the dynamic yield strength of stainless steel. On the other hand, TiAl as a semi-brittle material did not show surface depression. However, large amount of micro plasticity in the forms of miro-slips and twinning was detected on the surface of eroded TiAl, as shown in Figure 5-b. The formed asperities and the raised micro-slips are considered as the surface irregularities, which could be cracked and detached from the surface as shown in Figure 4.

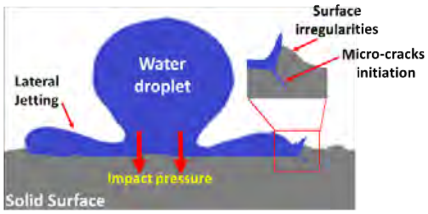

Figure 4. Schematic for the liquid/solid interaction during WDIE initiation

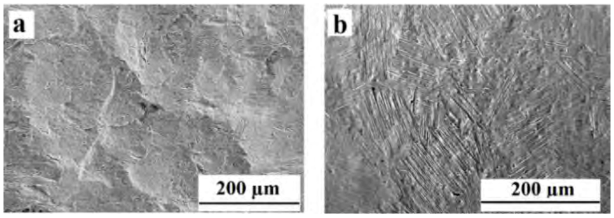

Figure 5. Slightly eroded surface in the incubation period of (a) Stainless steel and (b) TiAl.

CONCLUSION

Water droplet impingement erosion of three structural alloys were investigated. Their response to sub/supersonic impacts of water droplet were characterized. Microstructure of the solid materials and their mechanical properties in relation to impact pressures played notable role in damage evolution. A novel approach for representing WDIE results has been developed in this work. Introducing applied energy intensity as a new measure of erosion exposure and presenting erosion results in terms of applied energy intensity was found to be a comprehensive approach, as it covers most of impingement parameters. This approach enabled comparing results obtained using the same rig for different materials as well as comparing results from different rigs.

References

[1] Heymann F.J.: Survey of clues to the relationship between erosion rate and impact conditions, 2nd Meersburg Conference on Rain Erosion and Allied Phenomena, Bondensee, Fedreal German Republic, 1967.

[2] Mahdipoor M.S., Kirols H.S., Kevorkov D., Jedrzejowski P., Medraj M.: Influence of impact speed on water droplet erosion of TiAl compared with Ti6Al4V. *Sci Rep* **5**, 2015.

[3] Kirols H.S., Kevorkov D., Uihlein A., Medraj M.: The effect of initial surface roughness on water droplet erosion behaviour, *Wear* **342-343**:198-209, 2015.

[4] Mahdipoor M.S., Kevorkov D., Jedrzejowski P., Medraj M., Water droplet erosion mechanism of nearly fully-lamellar gamma TiAl alloy. *Mater Des* **89**: 1095-1106, 2016.