Influence of Rainfall Intensity on Erosion of Materials at Supersonic Velocities

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Theme

As the velocities at which erosion investigations are conducted has increased, the measurement of erosion mass loss has been found to be influenced by the concentration of water or other particulate matter which the material encounters. This synoptic presents results from rocket sled rain erosion tests at 4000 fps which demonstrate that the influence of rainfall concentration on the rain erosion mass loss of materials is linear over a concentration variation from 3 to 8 g/m^3 in this speed regime. These concentrations are typical of heavy naturally occurring precipitating environments. The analysis includes the influence of shock layer shielding and the variation of mass loss with impingement angle.

Contents

Measurement of erosion of materials by encounter with hydrometeors using current research facilities may require concentrations of particulates (rain, dendritic ice crystals, or platelet ice crystals) which are unrealistic compared to natural environments and which can lead to scaling errors.

The most commonly used evaluation technique for high velocity (greater than 6000 fps) is the ballistics range in which a model of the material is fired from a light gas gun through an artificial simulated rain environment and the surface recession (and calculated mass loss) is obtained from high-speed photographic measurements and/or recovered models. If the rain concentration is greater than 10 g/m^3 as it often must be in order to obtain sufficient recession on the model tip to measure photographically, then a mass loss ratio (mass eroded/mass encountered) is measured which is less than that measured in more tenuous environments such as those in actual flight tests. This is believed to be due to shielding of the material surface by debris from the particle (water layer) and ejecta from the craters in the target material.[1]

A recent test at Holloman Air Force Base using the rocket sled track[2] with its new rainfield has provided the means of investigating rain concentration effects in another simulated rainfield environment. Formerly, the spray nozzles (Spraying Systems Company Veejet 1/4-U8070) were arrayed on either side of the track on four foot standpipes at 4-ft intervals alternating side-to-side along the track and sprayed upward with a fanlike spray which then fell on the track. When operated at 9 psi, which was necessary to cover the test area of the track, the resulting rain concentration was 7.8 g/m^3 or 5.5 to 6.5 in./hr rainfall intensity with a mean drop size of 1.9 mm diam.

With the new rainfield installation, the nozzles are mounted immediately above the track at 8 ft height and spray downward toward the rail. This arrangement enables the nozzles to be operated at 5 psi and the resulting concentration is 3.1 g/m^3 or 2.5-3.5 in./hr with a mean drop size of 1.37 mm diam (see Fig. 1).

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To assess the effect of rainfield concentration and the other changes in the simulated environment, a run was scheduled at Mach 4.0 utilizing the AFML wedge fixture[3] which contains 48 specimens (12 each at 13.5°, 30°, 45°, and 60° impingement angles measured from line-of-flight). The materials chosen for this investigation included monolithic ceramics, bulk plastics, reinforced plastic laminates, and reinforced ceramics. A large body of erosion data exists for these materials at velocities from 1600 to 5500 fps and, hence, a direct comparison of the influence of the rainfall intensity is possible.[4]

To obtain the Mach 4.0 velocity for this test, the wedge device is mounted on the front of a Gila IV rocket motor which is the sustainer stage; 6 HVAR motors form the booster stage. The velocity peaks at rainfield entry and decreases from there. The conditions under which the various materials were exposed to the rain environment were identical in all respects with only the rainfield concentration change.

The data for three materials are summarized in Table 1 for the high (7.8 g/m^3) and low (3.10 g/m^3) water concentration environments. The data are presented in the form of mass loss ratio (mass eroded divided by mass encountered), G. The mass loss is determined by pre- and post-test weight measurements on the samples which have been dried overnight at 125°F. The mass encountered is calculated from the water concentration and the swept volume a particular

The positions of the 30° and 45° specimens on the wedge relative to the shock layer require that the data be corrected for shock layer shielding. This has been done in the manner of Reinecke and Waldman[5] using measured shock distances and oblique shock distances and oblique shock relations for drop breakup. Results are shown in the table, where z is the ratio of mass actually hitting the surface to the mass that would hit in the absence of the shock layer. Thus, G/z is the mass loss

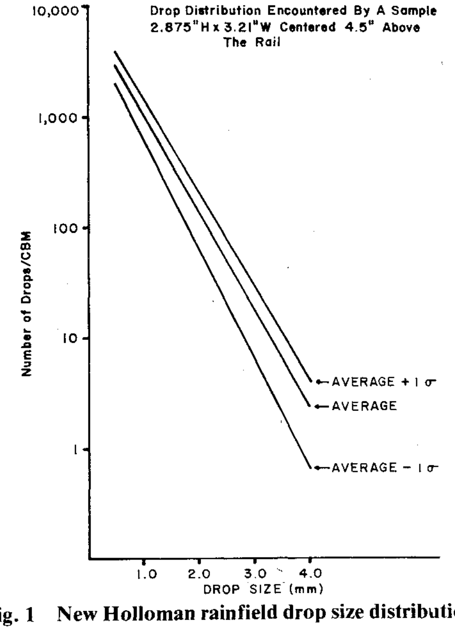

Fig. 1 New Holloman rainfield drop size distribution.

Table 1 Mass loss ratio comparisons corrected for shock layer shielding

			7.8 g/m^3 test conditions			3.10 g/m^3 test conditions		
Material	Angle	z	G/z	n	r	G/z	n	r
Teflon (TFE)	13.5	0.94	0.64-0.71	1.1	0.95	0.47	0.8	0.98
	30	0.33	1.08-1.79			0.75		
	45	0.60	2.39-2.59			1.29		
	60	0.87	2.41			1.35		
Glass	13.5	0.94	0.56-0.70	0.9	0.95	0.62	0.6	0.77
Epoxy	30	0.33						
Laminate	45	0.60	1.68-2.05			1.86		
	60	0.87	1.46-2.21			1.05		
Angle	13.5	0.94				1.38	1.0	0.97
Interlock	30	0.33				2.90		
3D Quartz	45	0.60				3.37		
Silica	60	0.87				6.12		

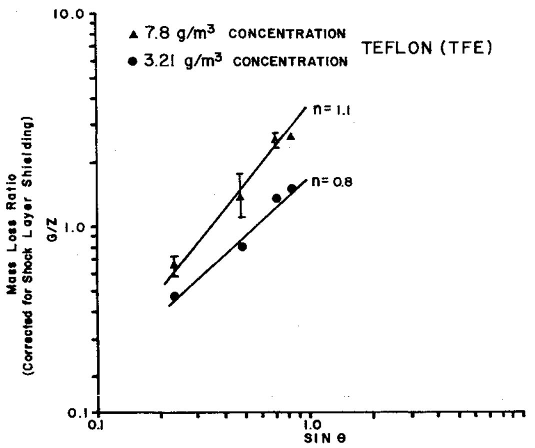

Fig. 2 Angle dependence for mass loss ratio of Teflon.

ratio based on the amount of water that actually hit the samples. The corrected values of mass loss ratio G/z bring the 30° data into substantial agreement with the data at other angles. Also given in the table are the exponent of the sine of the impact angle n obtained from a least squares regression analysis of the data, and the correlation coefficient r of the regression.[6] The exponent on the sine of the angle is very close to one except in the case where the data did not correlate well with the angle ($r=0.77$). The data are summarized in Fig. 2 for Teflon and for all materials in the table.

One of the most interesting subjects in erosion research is the influence of rain concentration or rapidity of impacts on the erosion behavior of materials. The correlation of single particle experiments in which the erosive particles are fired at the target and the rankings which result from them to multiple impingement experiments like the rocket sled or the ballistics ranges is also linked to this question. The single particle tests are widely used for hypersonic erosion tests because of the high costs of multiple impact experiments.

Another controversy concerns the linearity of rain concentration effects. That is, will the erosion in a rainfield half as intense be reduced to half that at the higher intensity? Integral with this question is how this varies from material class to material class.

If the rainfield concentration decrease which resulted from the new Holloman installation resulted in a decrease in the debris shielding on the aft specimens (due to less eroded fragments and/or thinner water layer), this would show up as a proportionately higher erosion mass loss of the specimens exposed to the less intense rain. The shock layers would be the same in either test and the other effect would be due to the decrease in average drop size distribution which might result in a lower fraction of unfragmented or partially fragmented drops reaching the specimen. This would tend to cause a lower mass loss.

However, if one examines the mass loss ratio data in Table 1 there is no discernible disproportionate decrease or increase in the mass loss ratio for the 30° or 45° specimens. Hence, a change in debris shielding is not observable under these velocity-rainfield concentration conditions or the debris shielding and drop size reduction effects are offsetting.

It does appear that the rainfield concentration effects are somewhat linear as to the resulting erosion. If one examines the data on Teflon and glass-epoxy laminates which erode uniformly without breakage or large-scale loss of material, the mass loss ratio in the 3.10 g/m^3 rainfield is approximately half that in the 7.8 g/m^3 environment.

On the other hand, many of the monolithic ceramics such as Pyroceram 9606 and fused silica which do not erode but catastrophically fracture when hit by rain drops at 4200 fps, show this fracture and mass loss in either environment. This is to be expected since the first drops seem to cause the fracture and that would happen with either concentration. Another observation which supports this point is that the very resistant monolithic materials such as alumina and beryllia which are relatively undamaged by the short exposure at Mach 4.0 are not significantly different after either exposure.

It thus appears that the erosion mass loss at 4500 fps varies with approximately the sine of the impingement angle. The mass loss is approximately equivalent to the mass encountered (up to a factor of 3) in this speed regime. With a decrease of one half in rainfield concentration under the aerodynamic/heating/flow conditions on the Holloman rocket sled track, the influence of concentration effects was linear and changes in debris shielding were not discernible.

References

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