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EXPERIMENTAL IMPACTS INTO TEFLON TARGETS AND LDEF THERMAL BLANKETS;

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INTRODUCTION: The Long Duration Exposure Facility (LDEF) exposed ~20 m^2 of identical thermal protective blankets, predominantly on the Ultra-Heavy Cosmic Ray Experiment (UHCRE; [1]). Approximately 700 penetration holes >300 µm in diameter were individually documented, while thousands of smaller penetrations and craters occurred in these blankets [2]. As a result of their 5.7 year exposure and because they pointed into a variety of different directions relative to the orbital motion of the non-spinning LDEF platform, these blankets can reveal important dynamic aspects of the hypervelocity particle environment in near-Earth orbit (*e.g.,* [3,4,5]). The blankets were composed of an outer teflon layer (~125 µm thick), followed by a vapor-deposited rear mirror of silver (<1000 Å thick), that was backed with an organic binder and a thermal protective paint (~50-75 µm thick), resulting in a cumulative thickness (T) of ~175-200 µm for the entire blanket [6]. Many penetrations resulted in highly variable delaminations of the teflon/metal or metal/organic binder interfaces that manifest themselves as "dark" halos or rings, because of the subsequent oxidation of the exposed silver-mirror [6]. The variety of these dark albedo features is bewildering, ranging from totally absent, to broad halos, to sharp single or multiple rings [2,6].

We previously reported [7] on the behavior of pure Teflon^{FEP} using ~6 km/s soda-lime projectiles. Over the past year we have conducted similar experiments over a wide range of velocities (*i.e.,* 1-7 km/s) to address velocity dependent aspects of cratering and penetrations of teflon targets. In addition, we experimented with real LDEF thermal blankets to hopefully duplicate the LDEF delaminations and to investigate a possible relationship of initial impact conditions on the wide variety of dark halo and ring features.

CRATERING EXPERIMENTS: Craters in massive Teflon targets are characterized by frayed, fibrous, highly irregular crater bottoms and walls that form a poorly defined central cavity, which is surrounded by a relatively large, well defined spall zone (see [7]). Figure 1 illustrates the velocity dependence of crater diameter (D_c; measured at the original target surface) and of the spall zone (D_s; average diameter of highly scalloped failure surface). All experiments utilized soda-lime glass projectiles 3175 µm in diameter; experiments requiring projectile velocities >3 km/s were performed with a 5 mm light-gas gun, while a powder-propellant gun was utilized for lower velocity projectiles. For comparison, we include the general cratering equations by Watts *et al.* [8]. The agreement is fair as the crater diameter data of [8] lies between our D_c and D_s measurements; this discrepancy may -- in large part -- result from operator-dependent idiosyncrasies in the definition of D_c. In any case, a linear regression line through the experimental data yields a slope/exponent of 0.441 for the velocity dependence of crater-size in Teflon^{FEP} targets.

PENETRATION EXPERIMENTS: Penetrations of teflon are characterized by the formation of substantial spall zones at the target's front and back side, with the latter always being the larger, especially for "massive" ($T > D_p$) targets. The prominent spallation from the target's rear leads to the unusual situation, albeit over a limited D_p/T range, that the penetration hole can actually be larger in diameter than the corresponding crater in infinite half-space targets [7]. Figure 2 illustrates penetration-hole diameters (D_h) in teflon targets of variable thickness (T) using the 3175 µm soda-lime glass at systematically different velocities of 2.3, 4.0, 6.3 and 7.0 km/s. The format of this plot (see [7]) is such that one may solve for the unknown parameter D_p from the measurement of hole diameter (D_h) and target thickness (T) on space-exposed surfaces, assuming some modeled velocity. Unfortunately, the circumstance that the hole diameter can be larger than the crater diameter causes the curves to be somewhat wavy, unlike aluminum [7], yet this effect becomes progressively less pronounced as velocity increases. Note that the velocity dependence for massive targets is substantial. At any fixed D_h/T, diameter D_p systematically decreases with increasing impact velocity. In contrast, for very thin films this velocity dependence diminishes and essentially vanishes at $D_p/T > 50$ (*i.e.,* approaching the condition of $D_h/D_p = 1$). The point: velocity matters a lot with massive targets, yet little to nothing when ultra-thin foils are being penetrated.

Having ranged from infinite half-space to penetrated targets also yielded the ballistic-limit thickness (T_{BL}) for penetrations of teflon at specific velocities; at 2.3 km/s this limit was reached at $D_p/T = 0.29$, whereas it is at $D_p/T = 0.15$ for the 7 km/s case. Although T_{BL} of the intermediate velocities would nicely comply with a linear regression defined by the above velocity endmembers, such a linear extrapolation to cosmic velocities is almost certainly incorrect, because the regression would be strongly affected by modest velocity (<4 km/s) data that do not reflect expected high velocity behavior [9].

EXPERIMENTS WITH LDEF BLANKETS: We intially experimented with pristine, unexposed samples of LDEF blankets, and were unsuccessful in duplicating the dark-albedo delamination features, despite extensive efforts at different projectile velocities (1-7 km/s), projectile sizes (50 to 3175 μm) and projectile densities (from 1 to 8 g/cm^3; nylon, glass, aluminum, alumina, brass, steel). We had no problem in producing faint rings as reported by [10], yet these features are quite different from the dark-albedo features of the space-exposed LDEF blankets. We concur with [6] that space exposure must have "pre-conditioned" and somehow weakened the teflon/Ag bonding (without specifying the actual mechanism to accomplish this). Therefore, many of the above experiments were repeated utilizing target specimens cut from space-exposed, and supposedly "preconditioned" LDEF blankets. Unfortunately, we still could not duplicate the concentric dark-albedo features. Assuming that temperature might have played some role, we conducted experiments with pristine and exposed foils cooled to -80^0 C at the time of impact, none of which yielded the desired delaminations. We are currently preparing to perform similar experiments at "elevated" temperatures. The nature of the dark-albedo features on the LDEF teflon thermal blankets remains enigmatic, at present.

Nevertheless, most of these blanket experiments also served as "calibration" experiments to test the assumed equivalence of pure Teflon^{FEP} and the composite LDEF thermal blankets. Absolute and relative dimensions of the LDEF blanket penetrations are indistinguishable from those of pure Teflon^{FEP}.

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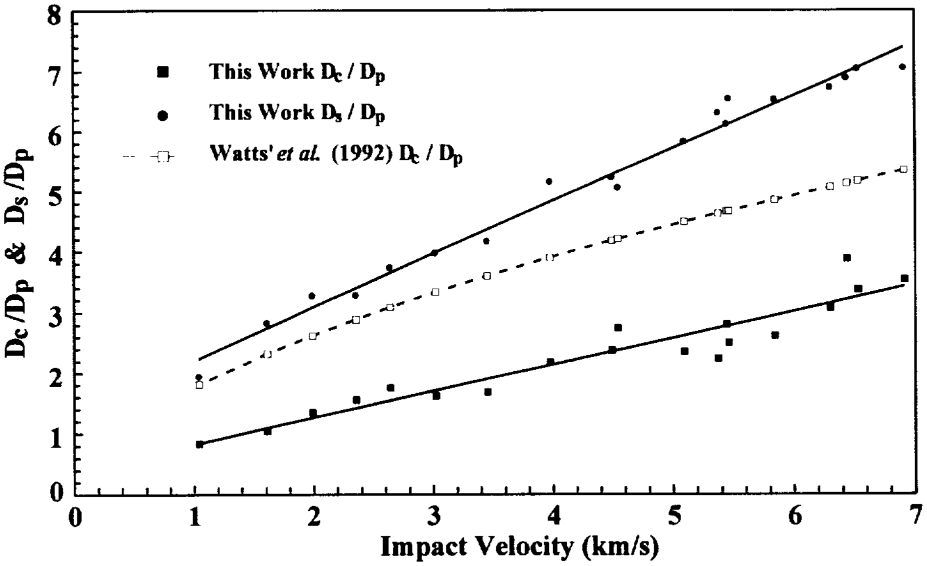

Figure 1.

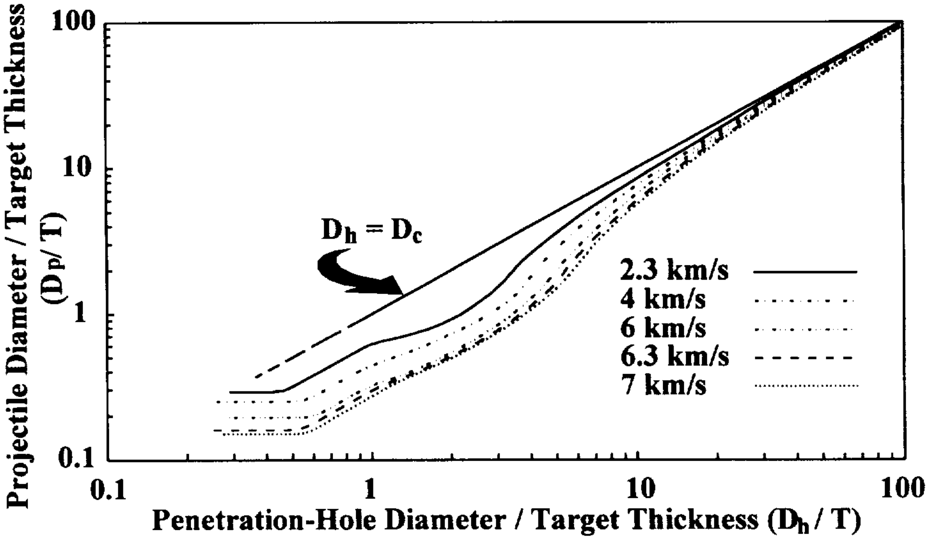

Figure 2.