EROSION MODELING OF 2D HOMOGENISED COMPOSITE MODEL

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ABSTRACT

Material loss due to the repetitive impact of unwanted solid particles present in the atmosphere causes wear. Leading edge erosion due to the solid particle is a challenging problem in aerospace fields. The finite Element (FE) approach is used to predict the underlying mechanism of erosion on a Homogenised composite model (HCM) made up of 2D Woven Glass fiber polymer. The erodent is made up of steel with a 50µm diameter. Six spherical eroding particles are used as an impactor on HCM at a velocity of 60 m/s in the z-direction. The erosion prediction is carried out at different angles of impact from 15° to 90° at an interval of 15°. The maximum mass loss occurs at 30° angle of impact, implying that the erosion mode is ductile. The model is able to capture the trend of mass loss with experimental results.

1 INTRODUCTION

Material degradation is one of the most challenging problems in the engineering field. Erosion is the process of material loss due to the impact of multiple solid particles on the target body. Helicopter rotor blades and wind turbine blades are prone to leading edge erosion as it operates in an extreme environment [1]. The material degradation due to solid particle erosion (SPE) is greatly influenced by impact angle (α), impact velocity, erodent geometry, etc. Two types of impact have been reported in the literature – normal ($\alpha = 90°$) and oblique impact ($0 < \alpha < 90°$) [2]. The very low magnitude of Impact velocity cannot cause plastic deformation, and corresponding wear is initiated by surface fatigue, whereas the high velocity of the impact causes plastic deformation [3]. The behaviour of erosion is categorized into mainly two types as per impact angle – Ductile and Brittle modes of erosion. If the mass loss is maximum at an impact angle of 30° then the erosion behaviour is named as ductile whereas brittle behaviour is observed for 90° [4-7].

Composites are nowadays playing a vital role in engineering applications, especially in aerospace, because of their low weight, superior strength-to-weight ratio, etc. The lightweight nature of composite materials and the need for increased efficiency of energy help aircraft consume less fuel and emit less CO_2 [8]. Composites made of unidirectional (UD) glass fiber (GF) is highly erosion resistant than any other composite materials [9]. The 2D woven composites possess better elastic properties over the UD composite as UD composites show better elastic properties in the longitudinal direction but are weak in the transverse direction, whereas 2D composites exhibit balanced elastic properties in the in-plane direction and good out-plane direction. It has better resistance to damage, high toughness, etc [10].

Most of the experimental and numerical work related to solid particle erosion (SPE) is available in the literature for metallic and UD composites. Only a few researchers performed experimental studies on 2D woven composites in context with SPE [11]. There is a gap in numerical modeling for HCM made of 2D woven composites. The main objective of the current work is to predict erosion behaviour due to solid particle impact on the homogenised composite model made up of 2D woven composite. A further aim is to compare the experimental results to the full-scale erosion model at different oblique and normal impact angles for 60 m/s velocity.

2 EROSION MODELING

Erosion occurs because solid particles will be lakhs in number for a shorter duration. So, modeling such a big-size particle will be computationally costly. Therefore, to reduce the computational cost and time, energy-based scaling is used to find the approximate number of particles to be simulated for predicting the erosion on the composite model. In this scaling method, we assumed that the delivered kinetic energy (K.E.) per unit time per unit area of impact would be the same as an experimental and model case [12].

$$N_s = \frac{m_e v_e^2}{m_s v_s^2} \cdot \frac{A_s T_s}{A_e T_e} \cdot N_e \tag{1}$$

Where m is the mass of the erodent, v is the velocity of the impact by the erodent, T is the exposure time, and the subscripts e and s refer to the experiment and model, respectively. A_e and A_s are the area of the nozzle and the impactor, respectively. From equation 1, we will get the approximate number (N_s) of particles to be modeled for predicting erosion. Ajaz et al. have developed a model for predicting erosion as shown in equation 2 for full scale.

$$D = N_s * D_1 * \eta_s * \eta_k \tag{2}$$

Where D is the total mass loss, D_1 is the mass loss of 1st non-interacting particle, η_s is the substrate property ratio of the non-interacting particle, and η_k is the K.E. ratio of the interacting particle.

2 ANALYSIS

A homogenised finite element (FE) model for predicting erosion due to solid particles is designed in the Explicit Dynamics Tool of ANSYS 2020 R2 (Academic Version). The homogenised woven glass polymer composite plate is designed with a dimension of 1 mm x 1 mm x 0.5 mm, and the erodent particles are spherical in shape with a radius of 25 µm. The properties of materials modeling are taken from [13] with a volume fraction of 40 %. Their mechanical properties are shown in Table 1.

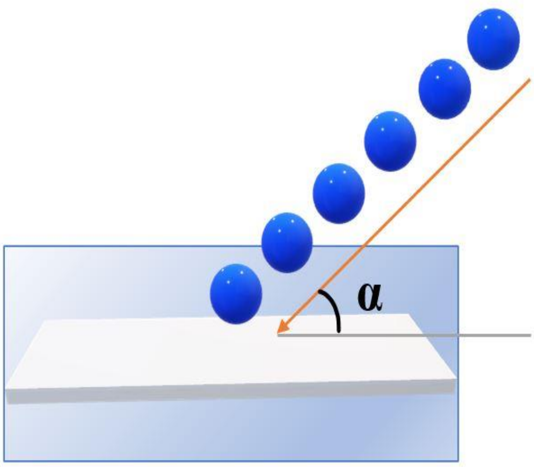

Figure 1: Composite model.

The mesh convergence study has been done to ensure that the obtained results are efficient and accurate. The HCM was meshed with different element sizes, as shown in Figure 2. The mesh converges from 0.0225 mm mesh size with a total number of elements of 46575. So, the HCM has linearly meshed with a dimension of 0.0175 mm x 0.0175 mm x 0.0175 mm. The target body is designed as a flexible body, whereas the erodent particles are designed as rigid. Proximity-based body interaction is applied between the erodent and the target body. All five sides of the composite model are restrained against deformation except for the top side, where the particles hit the target body. The failure criteria are based on the maximum stress theory. The elements are deleted from the HCM when the failure criterion is satisfied.

The FE simulation on the 2D homogenised model has been run for the velocity of impact as 60 m/s in the Z-direction to hit the target plate. The erosion prediction has been carried out at a different angle of impingement (α) ranging from 15° to 90° at an interval of 15° as shown in Figure 1.

Limit	Properties	Symbol	Unit	Values
Elastic	Density	ρ	g/cm^3	1750
	Modulus of Elasticity	E_{11}	GPa	20.8
		E_{22}		20.8
		E_{33}		8.7
	Modulus of Rigidity	G_{12}		3.92
		G_{13}		4.2
		G_{23}		4.2
	Poisson Ratio	ν_{12}	nil	0.173
		ν_{13}		0.279
		ν_{23}		0.279
Strength	Tensile Strength	σ_{T1}	MPa	250
		σ_{T2}		250
		σ_{T3}		27.1
	Compressive Strength	σ_{C1}		183
		σ_{C2}		183
		σ_{C3}		140
	Shear Strength	τ_{12}		28
		τ_{13}		28
		τ_{23}		28

Table 1: Material properties of Woven Glass fiber reinforced polymer.

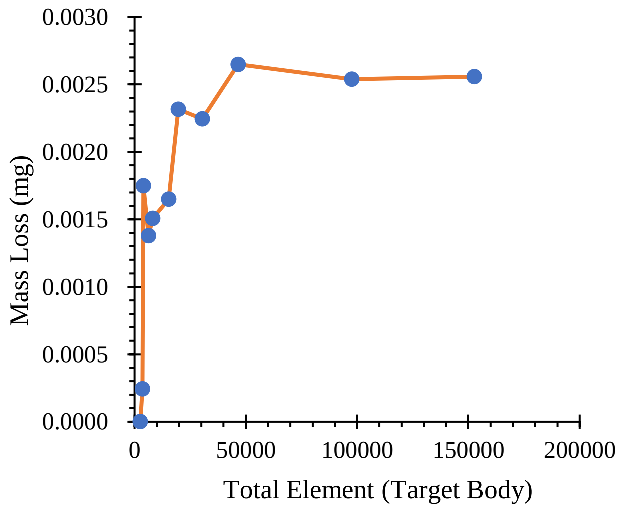

Figure 2: Mesh Convergence.

An experimental study is required for the validation of the numerical HCM. The erodent particle used in the numerical study is steel with a diameter of 50 µm. Six erodent particles were used to predict the erosion mechanism on HCM. The particle-to-particle distance is 0.1 mm. The total number of erodent particles for a 900-second duration in the experiment is about 1.72 x 10^8. The total number of impacts to be modeled (N_s) using equation 1 is 95804 to match the trend with experimental results.

4 RESULTS

The total element deleted data has been captured from the simulation directly. The cumulative mass loss has been calculated by multiplying the mass of the element by the total number of elements that have been deleted. The total duration of the simulation is 20 microseconds to impact the HCM. The erosion results have been shown in Figure 3 for different angles of impact. It was observed that no particle-to-particle interaction happens at a shallow angle (15°) of impact, which also matches the literature [12]. Collision due to particle-to-particle impact can be seen for higher angles of impact, say 30°, 45°, 60°, 75°, and 90°.

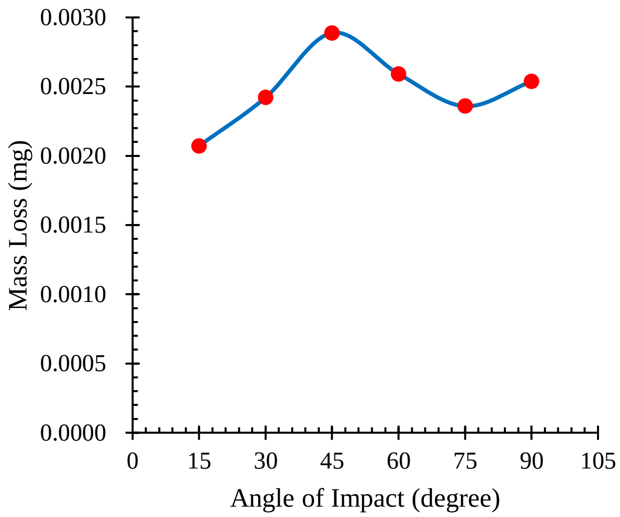

Figure 3: Cumulative mass loss with respect to different impact angles.

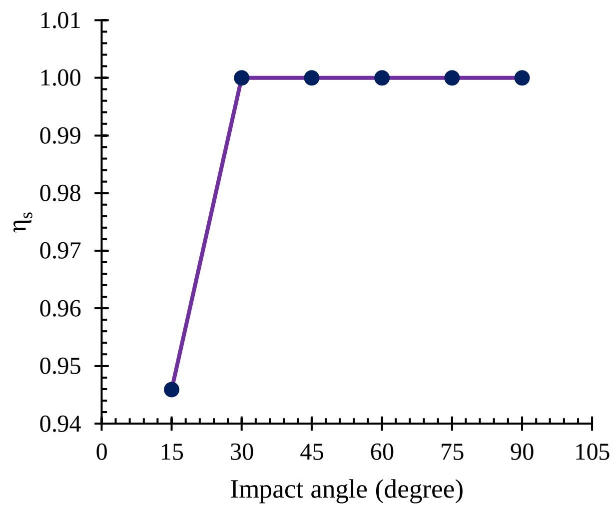

Figure 4: The plot showing variation of Substrate Surface Property ratio.

The non-linearity comes because the initial impact, which was non-interacting in nature, causes major damage to the HCM. The non-linearity is primarily caused by two factors that have been developed by Ajaz et al. The first factor is damage caused by the substrate because of the change in impact angle near the crater zone. η_s is the substrate surface property ratio and is defined by the ratio of damage that happens due to substrate surface damage to ideal damage. The η_s plot is shown in Figure 4. It has been clearly seen that the surface property ratio (η_s) tends to be constant for the higher angle of impact because of the particle-to-particle interaction.

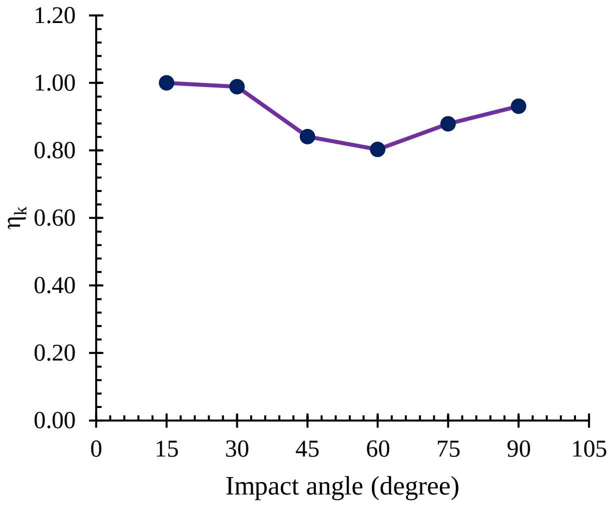

Figure 5: The plot showing variation of Kinetic Energy ratio.

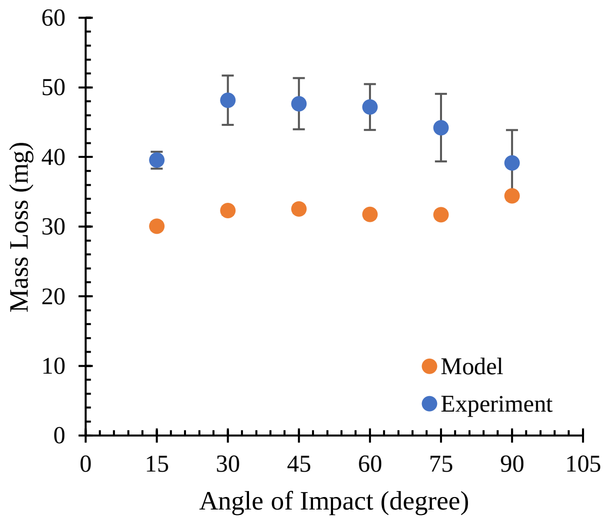

Figure 6: Full-scale prediction of mass loss.

When the HCM were impacted by an erodent, it returns back and hits the next particle. During the interaction, there has been a change in kinetic energy. As a result, the velocity of the particle gets lower compared to the velocity at the non-interaction stage. Velocity at different particle impacts has been tracked using simulation for different angles of impact. The second factor is known as the kinetic energy ratio (η_k). It is the ratio of the total kinetic energy of the particles to the ideal kinetic energy. It captures the dissipation of kinetic energy due to the interaction of particles. From the numerical study, it has been clearly shown that the particle bounces back after the interaction and has no contribution to the element damage of the HCM. At the lower angle of impact, particle-to-particle interaction has not been seen.

But for the higher angle of impact interaction starts from 1st particle. So, the kinetic energy ratios for a lower angle of impact will be higher compared to the higher value of impact which has been plotted in Figure 5. The prediction of a full-scale model has been calculated using equations 1 and 2. The trend of mass loss of the HCM is pretty close to that of experimental results as shown in Figure 6.

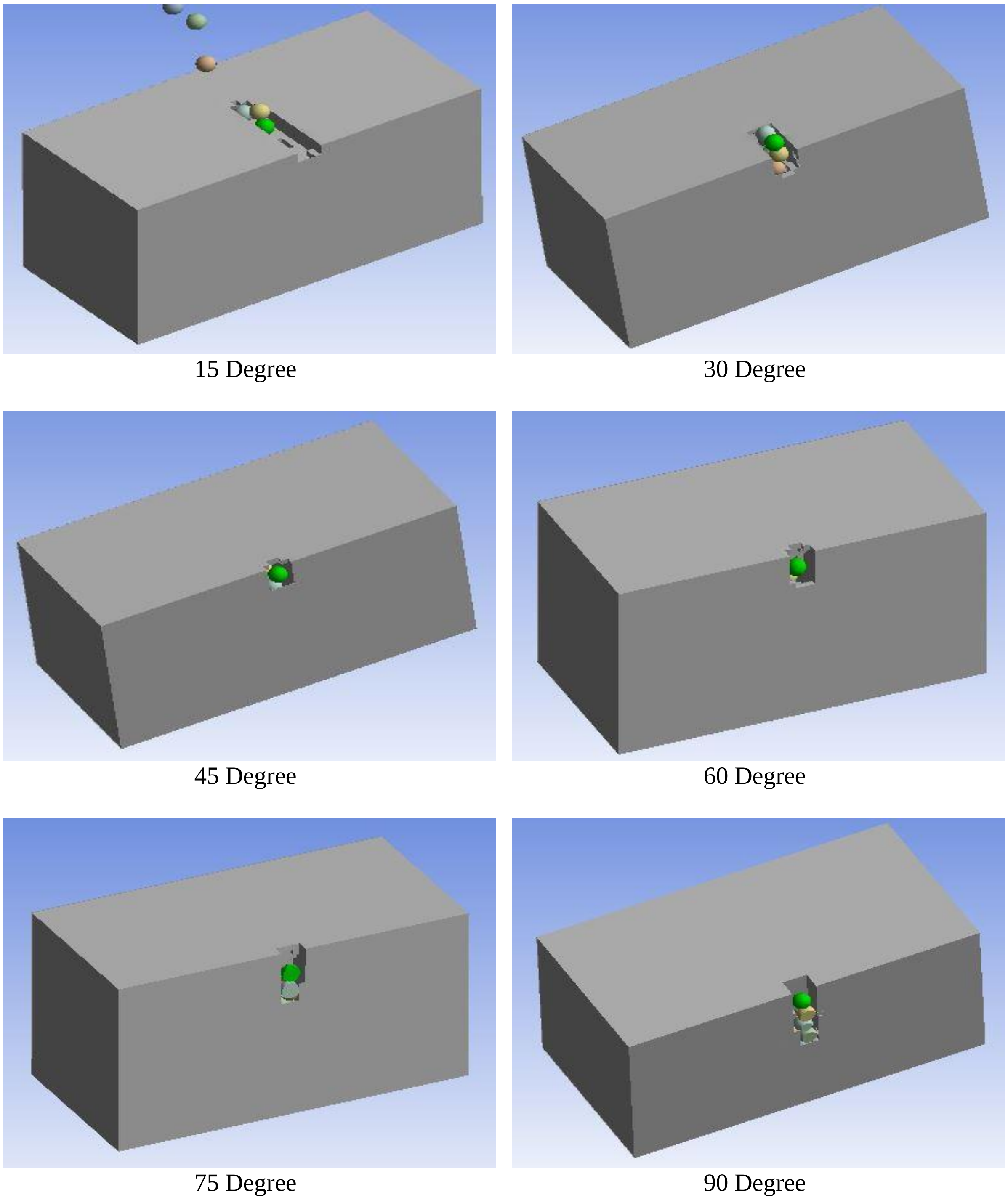

Figure 7: Damage pattern.

The damage caused at shallow angle is spread over the wide area of the top surface due to the rolling action of the eroding particle since particle-to-particle interaction has not been seen at 15° angle of impact. But, when the impact angle changes from shallow to deep (from 30° to 90°), the particle-to-particle interaction starts as a result, the damage is penetrating at a point in the direction of velocity of impact as shown in Figure 7. The corresponding mass loss is also less for higher impact angle as the major particles have not contributed to the deletion of an element of the HCM because these particle bounces back due to interaction.

5 CONCLUSIONS

The leading-edge erosion due to solid particle impact on helicopter rotor blades and wind turbine blades is a challenging problem. In this regard, numerical studies have been carried out to predict the erosion behaviour of Homogenised composite models (HCM) made with 2D woven Glass fiber composite. The maximum mass loss occurs at an impact angle of 30° which shows that the mode of erosion is ductile. The model is able to capture the trend of mass loss with experimental results. The prediction of mass loss may have a better fit with experimental results if we use a large number of eroding particles. The increase in particle-to-particle distance could be another possibility to have a better fit with the experimental results, as interacted particles can cause plastic deformation on HCM.

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