VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D.R.J. Owen (Eds)

SEMI-ADAPTIVE COUPLING TECHNIQUE FOR THE PREDICTION OF IMPACT DAMAGE

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Key words: Impact Mechanics, Sandwich Structure, Composite Materials, Adaptive Coupling, Smooth Particle Hydrodynamics (SPH)

Summary. *This work aims to present a novel semi-adaptive numerical coupling technique in which the finite element mesh is replaced by a discrete particle formulation in the failure region or damage zone at large strain. The prediction of impact damage of aramid paper honeycomb (NOMEX) cored sandwich panels under high velocity impacts have been investigated using the proposed semi-adaptive coupling technique. In the crush failure zone where the finite elements are replaced by discrete particles, the particles are compressed together by the compression stresses which allow stable computations without element elimination.*

1 INTRODUCTION

Sandwich structures are extensively employed in aerospace applications and the understanding of their impact behaviour is important for the further development of these structural components. A drawback of structural sandwich components in aircraft structures is their relatively low resistance to impact damage due to the thin outer composite skins. Despite extensive research and development of sandwich structures, their impact response is still not fully understood. When composite skin laminates are subjected to impact by a projectile, many of the fracture processes, with their associated energy absorbing capacities, can occur. Although the major damage mechanisms such as matrix cracking, debonding and fiber failure may appear individually, their interaction and the effects of fiber type and lay-up, distribution and geometrical nature, additionally the type and state of the matrix fiber resin bond and environmental effects result in complex failure modes. After fracture of the skin an impacting projectile may damage and penetrate into the core which then fails locally under combined compression/shear loads.

2 STATE OF THE ART

Since core deformation and failure are decisive for the energy absorption capability of sandwich structures, numerical problems such as element distortion in the core may lead to critical numerical instabilities and error termination. Additional computational techniques such as adaptive meshing with optimization of the mesh size or employment of different discretizations in different areas can create domain coupling problems. An alternative conventional numerical approach is Element Elimination Technique (EET) which is the removal of the finite elements on reaching a threshold stress or strain value. The disadvantage of this approach in the case of impact is that the failed material is contained mostly in the impact damage zone and contributes to the damage resistance even after the initial failure. Since EET progressively removes the elements from the impact zone, this numerical technique can not model the impact loading response realistically. Additionally small increments in the element elimination threshold may change the impact failure mode completely and this may lead to wrong numerical results.

3 AN ALTERNATIVE METHOD: ADAPTIVE COUPLING

To overcome the instabilities resulting from element based numerical methods several enhancement methodologies have been proposed. Among them meshless methods are employed in several engineering problems in which FEM has some deficiencies. However, meshless methods are relatively new and still under development thus they are often not robust enough for reliable numerical analysis. Therefore coupling between FEM and meshless methods is proposed as an efficient tool for current and future structural computations. Several coupling methods have been proposed to maintain the consistency and stability and to improve the efficiency of meshless methods. Coupling between FEM and SPH is one of the first coupling methods and some works have been devoted to show the efficiency of this coupling technique[1,2]. In these investigations coupling between FEM and SPH has been established using node-to-surface contact coupling algorithms. Beside direct coupling methods, adaptive coupling methodology is a novel coupling method which is based on replacement of the finite elements with discrete particles if the prescribed damage threshold has been reached. Sauer et al.[3] pointed out the numerical instabilities and the expensive use of the SPH method, and applied Moving Least Squares (MLS) correction methodology to improve the consistency of the meshless SPH approximation, so called MLSPH. Later, the same authors implemented an adaptive coupling of SPH particles with Lagrangian finite elements in the SOPHIA code[4]. Their investigations concluded that, compared to pure SPH discretization computational time is strongly reduced. The principle of their coupling algorithm is based on the extension of the SPH summation to all parts of the FE discretization inside the particle interaction radius. They computed penetration simulation to test their adaptive coupling methodology. Later they employed an adaptive node splitting and abovementioned adaptive coupling method to model the crushing behavior of Carbon Fibre-Reinforced Plastics (CFRP) material[4].

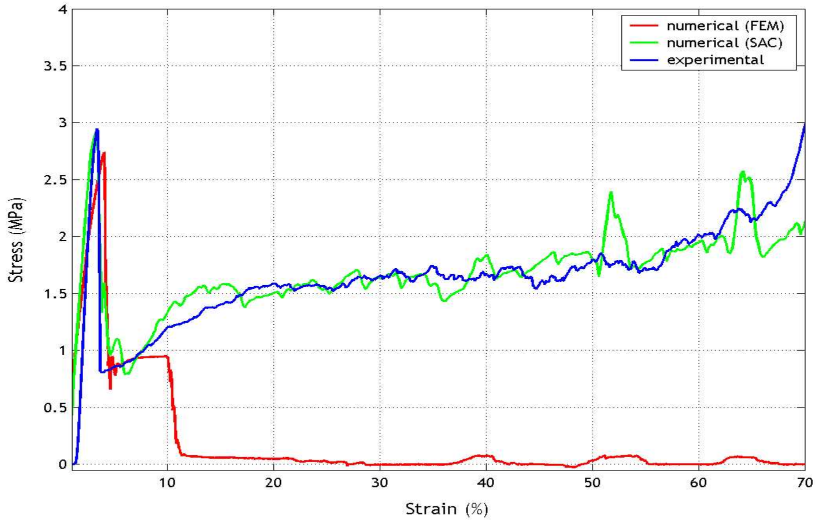

Figure 1: Comparison of strain vs. stress curves

4 SEMI-ADAPTIVE COUPLING TECHNIQUE

In this work a novel coupling technique so called *Semi-Adaptive Coupling (SAC)* Technique was used to model the impact damage of aramid paper honeycomb (NOMEX) cored sandwich panels. This technique consists in embedding the discrete particles inside the conventional solid elements and replacing the finite element mesh by a discrete particle formulation in the failure region or damage zone. Element elimination strain is used as adaptivity threshold.

5 RESULTS AND DISCUSSION

Hereby presented results are based on a previous experimental tests conducted at DLR on aramid paper honeycomb core, namely NOMEX cored sandwich plates. In the experimental component of this study, a series of tests were conducted to determine core properties under quasi static-compression and shear loads on sandwich specimens with carbon fibre fabric/epoxy facings. Fig. 1 shows the crushing response of NOMEX core under quasi-static loading and predictions from FEM and SAC models. FEM based numerical investigation removes the finite elements after reaching strain threshold and this causes lost contact information. Therefore after removal of damaged elements the numerically measured contact force drops down drastically. Alternatively, the SAC Technique has the advantage that by replacing elements with particles, these may be compacted under compression stresses, allowing stable computations, avoiding further element elimination and lost of contact force information. Furthermore the characterized material and model parameters may be used for impact loading cases.

A series of impact test was conducted for a sandwich composite plate with a 33mm

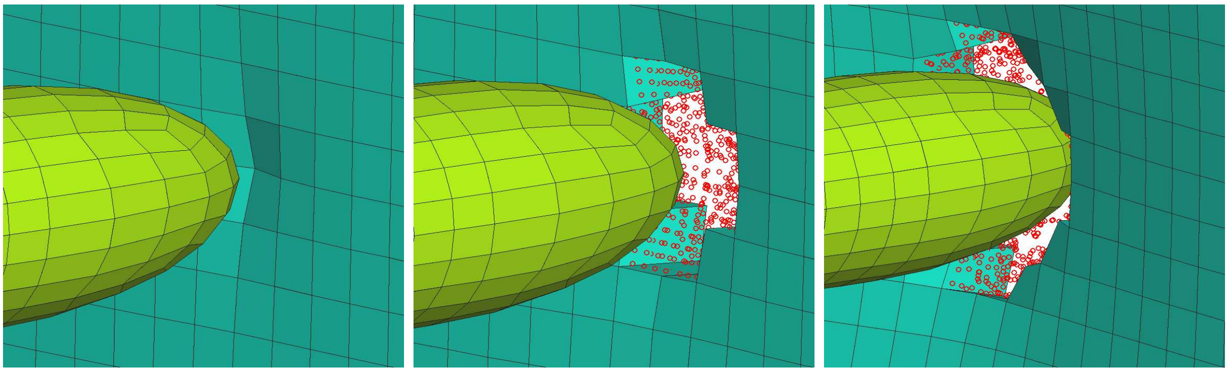

Figure 2: Evolution of semi-adaptive coupling in the impact failure zone

thick NOMEX core and $[0/45/0/45]_2$ carbon fibre fabric/epoxy facings with a nominal thickness of 1,6mm. Normal impact from a rigid impactor was considered at nominal impact velocity of 60m/s, which corresponds to the typical impact speed of runway debris on an aircraft structures during start and landing. Fig. 2 shows simulated penetration of the projectile into the sandwich core. Following upper facing damage the sandwich core is compressed by the penetrator and solid elements replaced with discrete particles after reaching an adaptivity threshold. Both observation and comparative investigations show that impact load cases may be modelled realistically using SAC technique.

6 CONCLUSION

We proposed a new approach called Semi-Adaptive Coupling (SAC) Technique to model the material response previously modelled using Element Elimination Technique (EET). SAC Technique replaces the eliminated elements by discrete particles and allow stable computation. The efficiency of the approach tested under both quasi-static and dynamic loading and showed good correlations with the experimental investigations.

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