Fig 5: Fuselage panels for the Airbus A350XWB manufactured using tape laying machines (Picture © Premium AEROTEC GmbH.)

3. Composites Revolution

Boeing 777 boasted an all-composite empennage and floor beams. The fiber resin system for Boeing 787 was kept the same but automated fiber placement techniques enable a weight saving of 20%. The automated fiber placement allows for rapid and accurate positioning of fibers onto a mandrel that creates the stringers and then spreads over the fuselage skin to varying thicknesses. Autoclave curing cures the epoxy resin after which the mandrels are disassembled and removed. The fuselage of the 787 is made in five different sections.

Composites allow for an appropriate increase of thickness in parts susceptible to high probability of impact damage such as doors, door surrounds, wing tips, wing leading and trailing edges and wing-to-body fairings are all prone to ground (service) vehicle impact damage. (Aircraft Technology Engineering & Maintenance, 2005)

Boeing 787 CFRP fuselage design braves larger pressures (from a cabin altitude of 8,000ft to a cabin altitude of 6,000ft) without adding much weight to the airframe structure. The outstanding corrosion resistance of composites has allowed Boeing to consider placing a cabin humidifier for making the passenger cabin environment more comfortable. Windows on the Boeing 787 are much larger than its predecessors. Airbus is driven by similar motivations for incorporating Fiber metal laminated (FML) composites in its new A350 (Aircraft Technology Engineering &Maintenance, 2005; Wall, 2005).

Dessault Aviation designed a one-piece business jet fuselage using pre-preg carbon fiber slit tape with honeycomb core. The single-piece manufacturability has drastically reduced simplified the structure by eliminating thousands of fasteners previously used in multi segment fuselage. (Leininger, 2005)

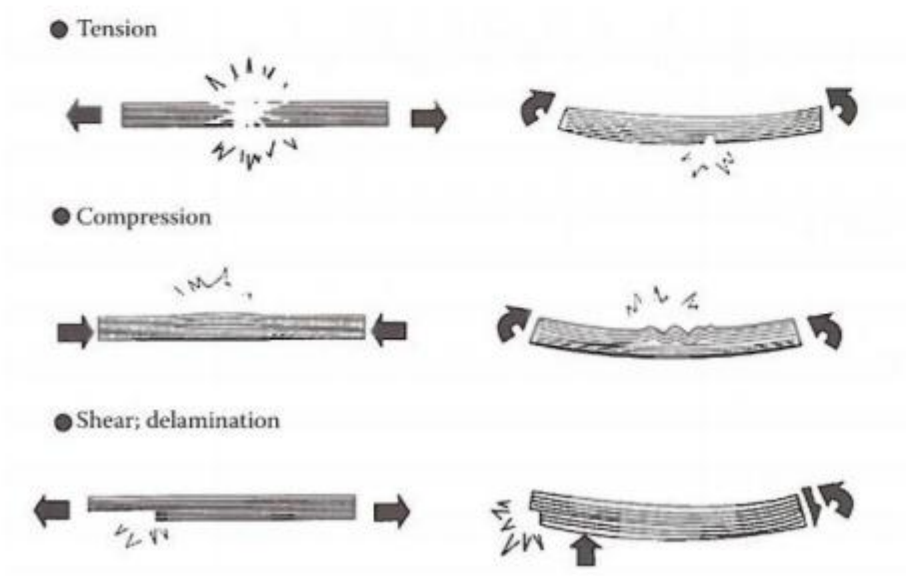

Fig 7: Failure modes of composite laminates (Gay and Hoa 2007)

Different failure criteria have been developed over time to explain the failure in composite materials. The most popular failure criteria are the maximum stress criterion, Hashin's criterion, Tsai-Hill criterion, Puck's criterion, Chang and Chang's criterion and maximum strain criterion. Hashin's failure criterion has been used by many researchers and it is one of the most reliable methods to predict the strength of laminated composites (Sun & Tao 1998).

Hashin's failure criterion was originally developed for unidirectional fibre-reinforced laminate. Even though a three-dimensional failure criterion is available, but it is limited to the scope of unidirectional laminates (Hashin and Rotem 1973; Hashin 1980). The criterion is based on two failure mechanisms which are associated with failure in fiber and failure in matrix, distinguishing in both cases between tension and compression.

Mechanical Properties of Fiber Metal Laminate

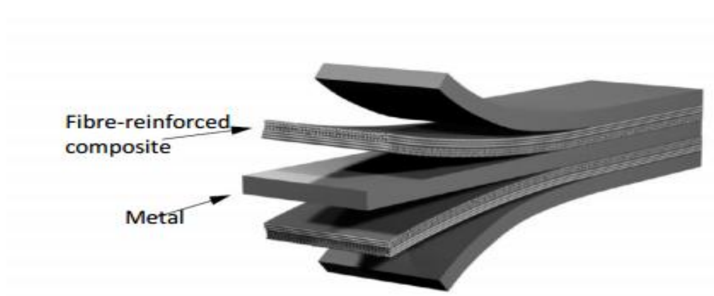

Fig 8: A typical Fiber Metal Laminate

8. Cocchieri, E.B. et al., 2006. A Review on the Development and Properties of Continuous Fiber / epoxy / aluminum Hybrid Composites for Aircraft Structures 2 . The Production of Metal / laminate Hybrid Composites. , 9(3), pp.247–256.
9. Khalili, S.M.R., Mittal, R.K. & Kalibar, S.G., 2005. A study of the mechanical properties of steel/aluminium/GRP laminates. *Materials Science and Engineering: A*, 412(1-2), pp.137–140.
10. Remmers, J.J.. & de Borst, R., 2001. Delamination buckling of fibre–metal laminates. *Composites Science and Technology*, 61(15), pp.2207–2213.

11. Sinmazçelik, T. et al., 2011. A review: Fibre metal laminates, background, bonding types and applied test methods. *Materials & Design*, 32(7), pp.3671–3685.

12. Chai, G.B. & Manikandan, P., 2014. Low velocity impact response of fibre-metal laminates – A review. *Composite Structures*, 107, pp.363–381.

13. Morinière, F.D., Alderliesten, R.C. & Benedictus, R., 2013. Low-velocity impact energy partition in GLARE. *Mechanics of Materials*, 66, pp.59–68.

14. Laliberté, J., Poon, C. & Straznicky, P. V, 2002. NUMERICAL MODELLING OF LOW VELOCITY IMPACT DAMAGE IN FIBRE-METAL-LAMINATES. , pp.1–10.

15. Cortés, P. & Cantwell, W.J., 2005. The fracture properties of a fibre–metal laminate based on magnesium alloy. *Composites Part B: Engineering*, 37(2-3), pp.163–170.

16. Vlot, A., 1993. IMPACT PROPERTIES OF FIBRE METAL. , 3, pp.911–927.

17. Robinson, A.G.M.M., Ioannidis, D.E.M.G.A.D.M.B. & Carruthersb, J., 1997. Review Crashworthy capability of composite material structures p. , 37, pp.109–134.

18. Vlot, A., 1996. Pergamon IMPACT LOADING ON FIBRE METAL LAMINATES simplified Von K ~ rmfin equations and also found in the work of Shivakumar et al . [5],. , 18(3), pp.291–307.

19. Vlot, A. & Krull, M., 1997. Impact Damage Resistance of Various Fibre Metal Laminates. , 7(1 997).

20. Lalibert, J.F., 2005. Impact Damage in Fiber Metal Laminates , Part 1 : Experiment. , 43(11).

21. Seyed Yaghoubi, a., Liu, Y. & Liaw, B., 2011. Stacking Sequence and Geometrical Effects on Low-Velocity Impact Behaviors of GLARE 5 (3/2) Fiber-Metal Laminates. *Journal of Thermoplastic Composite Materials*, 25(2), pp.223–247.

22. Sadighi, M., Alderliesten, R.C. & Benedictus, R., 2012. Impact resistance of fiber-metal laminates: A review. *International Journal of Impact Engineering*, 49, pp.77–90.

23. Aslan, Z., Karakuzu, R. & Okutan, B., 2003. The response of laminated composite plates under low-velocity impact loading. *Composite Structures*, 59(1), pp.119–127.