COUPLED THERMAL-ELECTRICAL ANLYSIS FOR CARBON FIBRE COMPOSITES EXPOSED TO SIMULATED LIGHTNING CURRENT

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SUMMARY

This paper presents numerical analysis methodology of transient temperature distribution in carbon fibre composites exposed to simulated lightning current. Coupled thermal-electrical analyses were conducted, and the numerical results are compared with the experimental results.

Keywords: Lightning strike, damage, carbon fibre composites, FEA, impulse current

INTRODUCTION

Lightning strike is one of the serious natural threat for composite aircraft structures. However, damage behaviour of carbon fibre composites without lightning protection system such as copper meshes has not been reported in detail, and few research papers on numerical analysis for the phenomena have been published [1,2]. This paper presents numerical analysis of transient temperature distribution in carbon fibre composites exposed to simulated lightning current, and the numerical results are compared with the experimental results.

NUMERICAL ANALYSIS

Material used in the experiments is carbon / epoxy (IM600/133, Toho Tenax), and Physical properties such as thermal conductivity, density, specific heat, and electrical conductivity were evaluated for each direction of the unidirectional composites (longitudinal, transverse, and through thickness). Thermal decomposition behaviour was evaluated using thermo-gravimetric analysis. The pyrolysis kinetics was also analyzed.

Simulated impulse current was applied at the centre of quasi-isotropic laminate ([45/0/-45/90]4s). Specimen had 100 mm in width, 150 mm in length, and 4.2 mm in thickness. Typical impulse current profile is

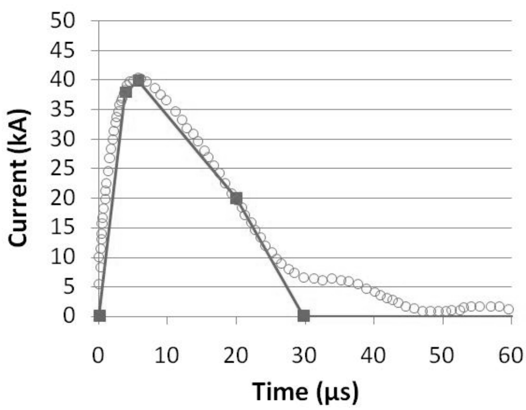


Fig.1 Typical impulse current profile

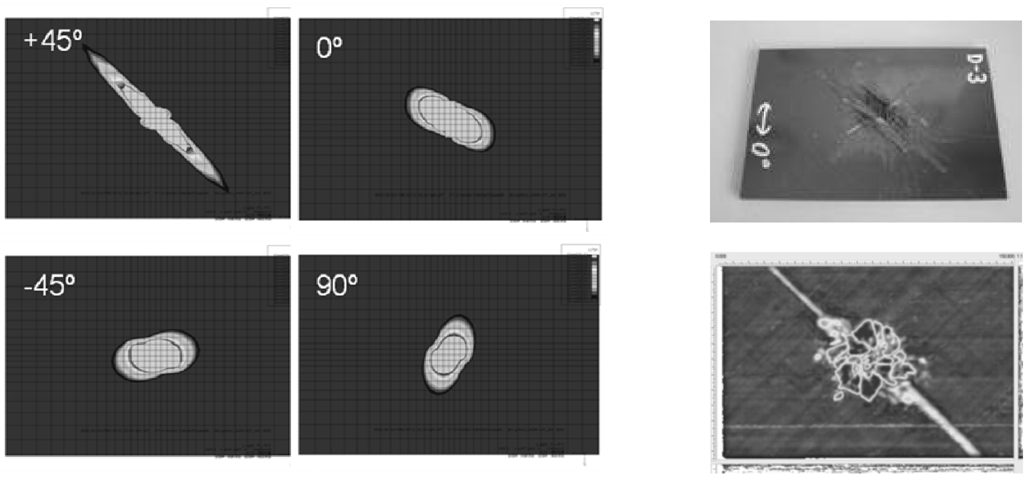
shown in Fig.1. Maximum current was 10, 20, 30, and 40kA.

Coupled thermal-electrical analyses were conducted using commercial finite element analysis (FEA) code “ABAQUS v6.8”. The electrical potential was calculated under the boundary conditions including electrical load, and then transient temperature distribution was calculated by applying Joule heat generation. The bottom and side surfaces were assumed to be zero potential because of electrical discharge at the side surfaces.

RESULTS

After preliminary numerical analysis, it was found that the maximum surface temperature exceeded 10000 K due to extreme high Joule heat. However, it was supposed that the maximum surface temperature is below 3300 K because of sublimation of carbon. Therefore the maximum temperature was limited by introducing latent heat.

Fig. 2 (a) shows the estimated damaged zone due to Joule heat. It was assumed that the damage occurred above 450^{o}C from the analogy of TGA results and thermal decomposition kinetics analysis. Fig. 1(b) shows ultra-sonic inspection result after impulse current testing. The damaged area and depth were also evaluated for other impulse current profiles. The geometries, dimensions of estimated damage area almost agreed with the experimental result. This suggests that the damages of carbon fibre composite laminates exposed to impulse current are mainly caused by sublimation of carbon fibre and decomposition of matrix due to Joule heat.



(a) Numerical results (estimated damaged zone) (b) Experimental result

Fig.2 Numerical and experimental results (40kA, T1/T2=2.6/10.5)

References

1. I. A. Metwally et al., Computation of transitent-temperature profiles in objects exposed to simulated lightning current, Proc of 2003 IEEE Bologna Power Tech Conference, June (2003).

2. M. Miller and P. Feraboli, Damage in composites under electrical loading, Proc of US-Japan Conf on Composite Materials (2008).