GLASS FIBER REINFORCED PLASTIC LAMINATE WITH SELF-DAMAGE ASSESSMENT CAPABILITY

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Keywords: *passive health monitoring, strain memory alloys*

Introduction

The increasing inclusion of composite laminates in safety critical structures has prompted the development of a variety of damage assessment or structural health monitoring techniques. Among the new technologies is a method suited to peak strain measurement by the use of strain memory alloy films embedded in the laminate at primary manufacturing stage. The metastable alloys that comprise the group known as strain memory alloys, are all ferrous based, relatively cheap to produce, and operate on the principle of crystal transformation from austenitic parent phase to martensitic product phase [1,2]. The martensite forms in direct proportion to the peak strain induced in the material, and the magnetic susceptibility changes in direct proportion to the amount of martensite that has nucleated within the material. The correlating change in magnetic susceptibility can therefore be monitored as an indication of peak strain, since the transformation is irreversible.

Smart Laminate Production

The possibilities for embedding strain memory alloy inserts into a laminate were originally thought to include foils and wire arrays. However, subsequent research has shown that the amount of martensite nucleated within foils is extremely small and requires specialized magnetic susceptibility measurement. The volume of martensite produced in a wire would therefore be too difficult to measure economically and feasibly in an industrial situation.

The inserts are added to the laminate at primary manufacturing stage and show no sensitivity to cure procedures. The bonding of the laminate to the insert also did not present any problems, provided that good manufacturing practice was followed. A variety of film geometries have therefore been embedded in glass fiber laminates at a variety of depths. That is, the inserts were embedded (in the centre) into laminates of 10 and 16 layers of unidirectional glass fiber and epoxy resin. The test pieces took the form of a tensile specimen into which a foil also of "tensile-testpiece" geometry (as shown in figure 1 below) was embedded. The inserts varied from having a straight gauge length, to a damage concentrator of 5mm, 10mm, and 20mm. Thus two variables were evaluated for their influence on the ability of a strain memory foil to indicate damage within the laminate: the distance of the sensor from the insert from the surface (and therefore the magnetic susceptibility meter) was the first variable, and the influence of the presence of a damage concentrator on martensitic nucleation was also investigated.

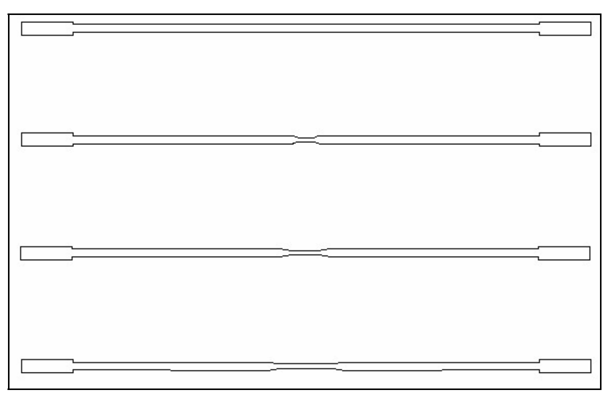

Figure 1: Smart insert geometries that were embedded in the laminates.

The material used for the smart inserts was in fact a form of 304 stainless steel that had been specially manufactured to very tight chemical tolerances, and roll processed to 0.2 mm thickness. It is well known that strain memory alloys can have their strength and transformation characteristics tailored to suit a given application, by warm working them (in the ausforming range of 450 to 550^{0}C) [1,2]. The warm working increases the dislocation density making transformation easier (steeper transformation curve) as well as increasing yield strength, while still maintaining the austenitic crystal structure upon quenching to room temperature. This warm working is not however kind to the rollers that perform the work and increases the cost of the material. For this set of experiments there was no warm work added to the material; it was simply annealed and quenched. The smart inserts were then cut from the foil using electro-discharge machining (EDM) so as not to induce any material transformation, which can happen when mechanical cutting procedures are used.

Results

A variety of magnetic susceptibility measurement techniques were considered, but the only feasible measuring device that had both the required sensitivity and the industrial robustness was in fact the commercially available geological susceptibility measurement device. This was kept as a constant distance from the laminate tensile test pieces as they were tested (permanently fixed to the Instron tensile test machine that performed the testing). The results show a direct almost linear correlation between the extension of the laminate and the change in the susceptibility of the smart insert. Figure 2 shows some of the results for the specimens that comprised 10 layers of glass and a smart insert possessing a damage concentrator 5mm long.

The rest of the results are presented in the full length paper, but can be summarized as follows: the presence of the damage concentrator definitely aided the indication of damage, in the sense that the martensitic nucleation was localized and concentrated in one easy to locate site, rather than being homogeneously precipitated along the whole gauge length of the smart insert. This resulted in higher susceptibility readings for the same extension, in the inserts possessing the damage concentrator, when compared to those not having the damage concentrator. This in turn yields greater resolution in determining the peak strain.

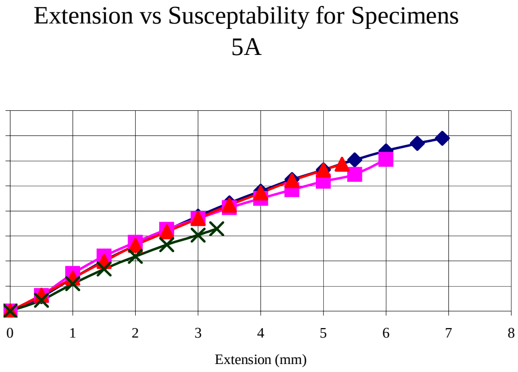

Figure 2: Susceptibility change with laminate extension.

Also evident from the full set of results was the fact that the distance between the susceptibility meter and the smart insert (in this case determined by the number of layers of glass) was an extremely sensitive variable. The magnetic susceptibility dropped by a factor of two for the laminates that had 16 layers of glass (and the same smart insert geometry) compared to the laminates with only 10 layers of glass.

Conclusion

Strain memory alloy foils can be used as an effective means for indicating damage in composite laminates [3], but the depth at which they are embedded and the presence of damage concentrators within the foil geometry, are both parameters that need to be carefully managed in order to attain the most sensitive result.

References

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