Formulation and Evaluation af a Novel Adhesive Film for Use in Composite Patch Repair

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Summary: The current work focuses on the testing of a novel material used as an adhesive film in Composite Patch Repair (CPR). A series of Differential Scanning Calorimetry (DSC) results along with various curing cycles not only led to the optimum material composition but also demonstrated the compatibility to the composite pre-impregnated patches. This in turn was subjected to mechanical testing including shear strength measurements. The substrate was chosen to be 2017 T4 aluminium alloy which is customarily used in the aerospace industry, taking into account that CPR is a technique mainly applied in this field. The subsequent surface preparation of the specimens was investigated for the specified context resulting to the selection of the Ferric Sulphate Sulphuric acid etching process. Finally, a series of specimens representing actual skin repairs were created and subjected to cyclic loading, specifying the suitability of the novel material, compared to commercially available materials.

Keywords: adhesive films; composite patch repair; differential scanning calorimetry; fatigue testing of bonded joints; shear strength

Composite Patch Repair-Scope

The current work focuses on cracked metallic skin configurations, repaired by means of bonded composite patches. Baker[1,2] has summarized the benefits of CPR. Furthermore, it is possible to perform in situ repairs, with the use of portable curing devices. This fact leads to substantial savings for the aircraft industry, as there is no need for disassembly of structural components and, consequently, aircraft down time is reduced. Composite patch repairs hold an esteemed position in the aerospace industry, due to the advantages offered to the damaged structure. Availability of high strength fibres and adhesives led to the viability of applying this technique to aerospace structures. CPR was first performed more than 30 years ago by RAAF.[3] Nevertheless this technique is only accepted and certified for secondary airframe structures.[4] Detailed knowledge of the mechanical response in service and advanced materials are the two most important fields in need of research so as to expand CPR to primary structure applications.

The primary material used in CPR is a series of Epoxy prepreg Carbon or Boron plies, bonded to the damaged structure by means of an adhesive Epoxy film (Figure 1).

The repair performs bridging of the loads from one side of the structural failure to the other, thus avoiding the damaged region. The adhesive Epoxy film carries the loads from the structure through to the patch by shear (Figure 2).

Objective and Specifications

The objective of this research was to produce a novel adhesive for the specified repair technique and compare the resulting overall performance related to commercially

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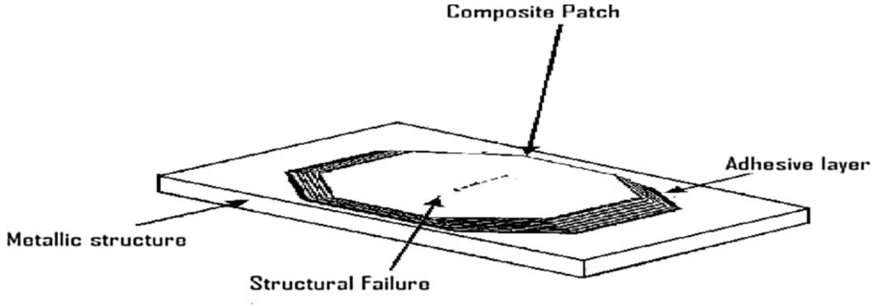

Figure 1.
Schematic representation of CPR.

available materials. The product specifications were:

1. Similar, if not advanced mechanical behaviour to commercially available materials.
2. Final form (prior to curing): Thin films (0.3 mm).
3. Compatibility to usual curing cycles.
4. Compatibility to composite patches.

Material Synthesis and Preparation

The Primaset monomer LECY (E) (4,4′-Ethylidenediphenyl dicyanate), Sigma product was used as is. Polysulfone, also a Sigma Product, with a molecular weight Mw = 35 kdalton was formulated in thin films, and at first was dissolved in dichloromethane (CH2Cl2) and afterwards was placed in Petri dishies, where it was left at rest until the solvent evaporated. The next step was to add the thin films in the monomer Lecy under mixing with a mechanical mixer at a speed of 1000 rpm and heating between 90 °C – 110 °C. The final mixture had a monomer/Polysulfone analogy of 85/15 (w/w) which is left to cool down to room temperature. Afterwards nonylphenol quantities (Sigma product) 100phr and Cobalt (II) catalyst acetylacetonate (Sigma product) 1000 ppm (calculated in relation to the per weight monomer) were mixed using ultrasonication for 5 minutes and heating at 45 °C for 30 minutes The next step of the process was to add the catalytic mixture to the preconstructed monomer/Polysulfone mixture at 45 °C and mix via ultrasonication for 5 minutes, thus producing a homogeneous brown mixture. The resulting compound is being heated at 60°–70 °C and entrapped air is rejected from the system by vacuum application. The final product is then kept at −15 °C.

Mechanical Testing

The testing of the material was designed according to CPR technique. One could

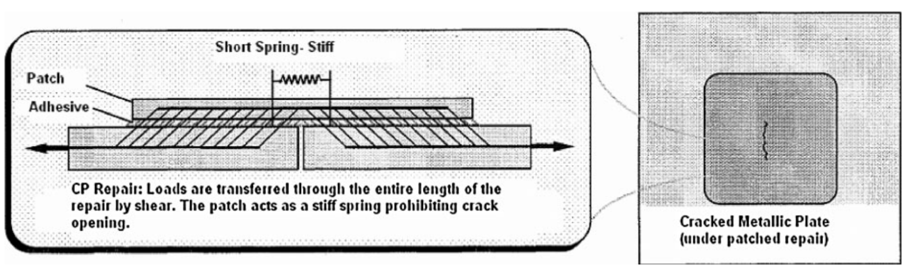

Figure 2.
Mechanism of load transfer in Composite Patch Repair.

state that the following procedures were "purpose specific", nevertheless obeying guidelines provided by the relative standards.

The loads in a CP repaired structure are transferred from the substrate to the composite patch through the adhesive film by shear. This fact leads to the need of specifying the shear strength of an adhesive for the particular application.

The applicable specimen standard was in effect.[5] The substrate was 2017 T4 Aluminium, an alloy that finds application in the Aerospace industry. Tabs were added to the specimens in order to alleviate out of plane bending. The strength and durability of such a repair depends on the adhesive and the substrate's surface pre-treatment. Many such processes have been developed, most of which are either complex in application or hazardous for the technician carrying out the repair procedure. Surface etching was selected to be the Ferric Sulphate Sulphuric acid process[6] following mechanical abrasion. The curing cycle time for these specimens was set by the commercially available products, which is a plateau at 120 °C for 90 minutes. The process was integrated to a "purpose specific" level by performing the curing process in a vacuum bag (as in CPR). Along with the DSC results, revealing the curing degree at various temperatures, it was of great interest to take into account the mechanical performance in terms of curing, as elevated curing does not necessarily translate to optimum strength. Four sets of specimens of the novel material were subjected to testing with curing cycles ranging from 120 °C to 180 °C. The temperature is limited to 180 °C as one must consider that elevated temperatures for CPR are not allowed in order to limit thermal stresses in the resulting structure.

Results

The mechanical testing was carried out in an Instron 1121 tension device (Figure 3). Tension was applied to the specimens up to the point of failure. The maximum load was recorded and along with the overlap area

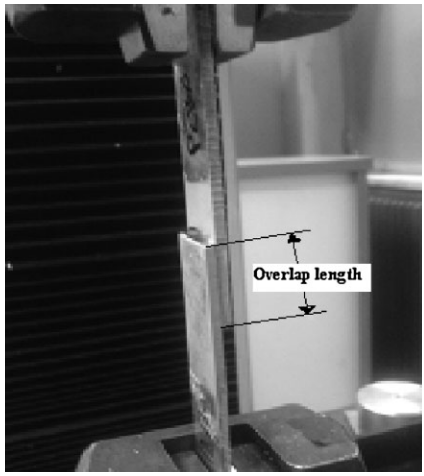

Figure 3.
Specimen under testing. The overlap length is identified.

(total area of adhesive application), the maximum stress was calculated.

The graph shows the resulting mean strength of the novel material sets (Figure 4). The results show that strength increases with higher curing temperatures. Nevertheless, the strength elevation from 160° to 180 °C is 0.15 MPa would not justify such a temperature increase.

Furthermore, the type of fracture was found to be mostly cohesive in all sets of specimens. To quantify the findings Scanning Electron Microscopy (SEM) was carried out for a number of specimens (Figures 5, 6).

Fatigue Loading

After having chosen the most suitable curing cycle for the novel material, the actual application was deemed obligatory so as to reach a wider comparison to FM 300-2 from Cytec, a commercial adhesive commonly used in such applications.

The adherent was 2017 T4 Aluminium strips with dimensions 300 × 80 × 3 mm (length × width × thickness) carrying a centrally located notch of 10 mm in length and 1 mm width, perpendicular to the direction of loading as seen in Figure 7.

Surface preparation was identical to the one followed for the single lap specimens.

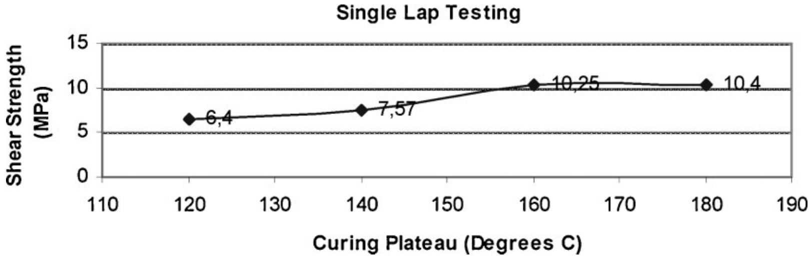

Figure 4.
Resulting strength of the novel material opposed to a range of curing cycles.

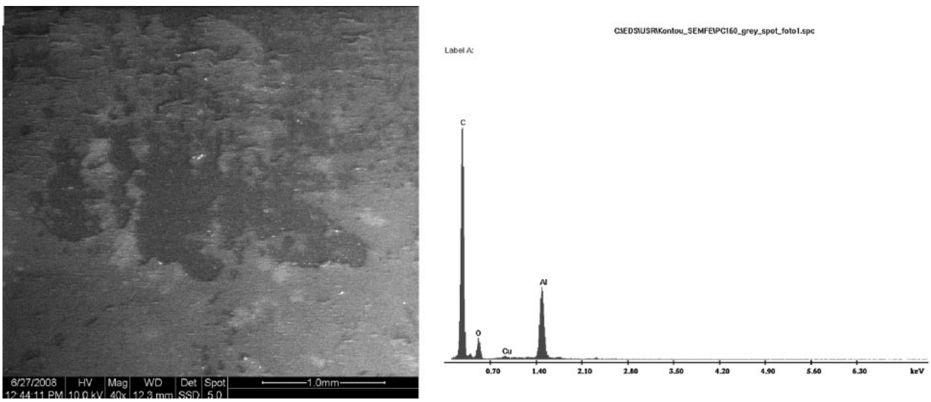

Figure 5.
160 °C 73% Cohesive failure.

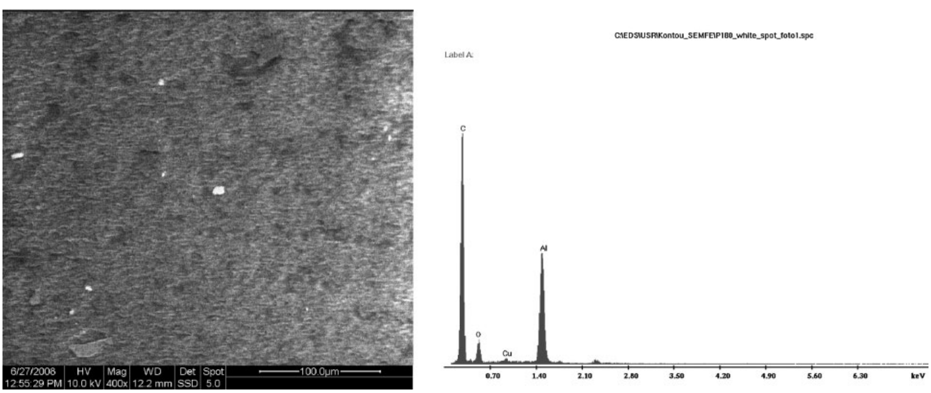

Figure 6.
180 °C 61% Cohesive failure.

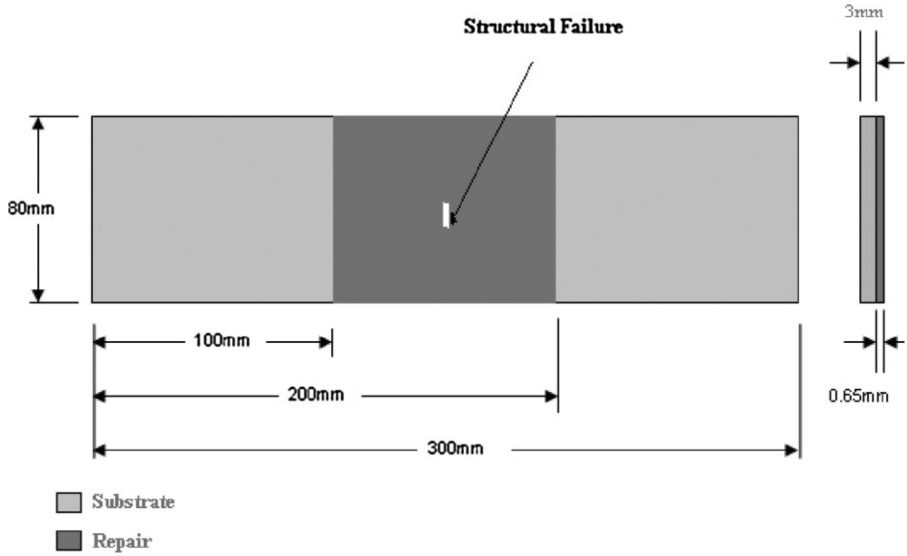

Figure 7.
Geometry of repair specimens.

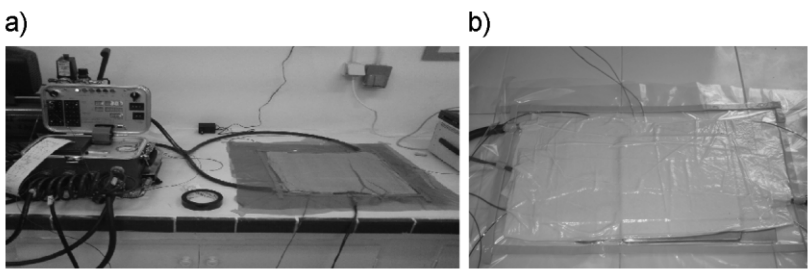

Figure 8.
a: ANITA Bonding Console b: Vaccum bag.

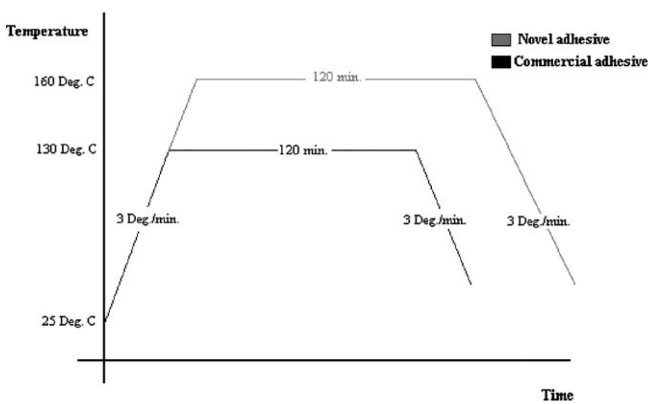

Figure 9.
Curing cycles followed in both variant configurations.

Figure 10.
Instron 8801.

The curing process was achieved with use of a portable curing device (ANITA OT) used in actual CP repairs in the industry (Figure 8).

The patch comprised of 4 unilateral plies of HexPly M20 supplied by Hexcel. The curing cycles were different (Figure 4) to the ones followed in the single lap specimen preparation as at this stage the commercial composite is to be cured as well.

Results

The testing was carried out in an Instron 8801 device (Figure 10) able of applying cyclic loading up to 10 tons. The Maximum stress applied corresponded to 45.2% (193.3 MPa) of the substrate's Ultimate Tensile Strength (UTS).

The loading amplitude was set to 13.2 kN. The frequency was set at 20 Hz. Room temperature was at 28 °C. The first series of specimens were not repaired in order to identify a baseline life. The second and third series were the repaired strips with the commercial and novel adhesive respectively.

Results obtained in fatigue performance can be seen In Figure 11. The plots were produced by representing specimens of each set. Half crack length (a) was documented along with crack initiation reaching final fracture of the plate (Half width = 40 mm). As it can be seen, both repairs performed in a similar fashion, finally offering an approximate 355% life extension compared to the non repaired configuration.

Conclusion

A novel material for use in CPR was composed. Shear strength was identified by means of purpose specific designed testing. The best curing cycle in terms of strength was identified to be at a plateau of 160 °C, 30 °C over the cycles proposed for most commercial materials. The ultimate experimental testing for the novel adhesive was application to the process of repair with composite patches. Results show that under dynamic loading, the configuration of the proposed adhesive offered similar life extension and in many cases, initially higher retardation of crack propagation as opposed to the commercial material.

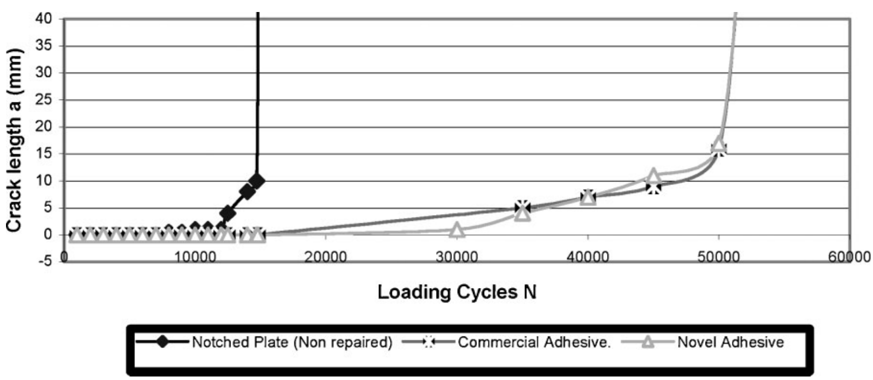

Figure 11.
Crack initiation and propagation corresponding to loading cycles.

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