Damage Characterization and Defect Study on Natural Fiber Reinforced Polymer Composite Using Infrared Thermography

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Abstract- *In a various engineering fields, composite materials are been replacing the conventional materials. During manufacturing of composites, imperfections appear on the composites due to various moulding parameters such as temperature, pressure and humidity. Imperfections observed on the composites include porosities and resin shrinkage during recurring. The presence of voids or cracks or inclusion in the composites can cause a sudden failure in the composites. There are several methods to characterize such defects. The main purpose of the present study is to investigate the imperfection on natural fiber reinforced polymer composites by using a non destructive testing method. This method is suitable to identify the random voids and its morphology and also the cracks in the natural fiber reinforced polymer composites non-destructively. IR thermography is a surface temperature measurement technique that is used to detect spatial variations observed in the surface of the composites. It reveals flaws by searching anomalous hot-spots after thermal excitation.In thermography the sample is been heated using an external heat source .The thermographic analyses were verified by using an optical microscope.*

Keywords- Epoxy Resin, Hand layup, Infra Red Thermography, Manufacturing defects, Natural fiber

I. INTRODUCTION

Composites are now widely used material because of their adaptability to different situations and it can be combined with different materials to give variety of properties.Various applications are aerospace,automobile industry and different infrastructure. Natural fiber composites include coir, jute, baggase, cotton, bamboo, hemp. Polymer matrix composite is widely used composites, because of its advantages such as great strength and stiffness along with resistance to corrosion. Thermosetting resins such as epoxy, polyester, vinyl ester are commonly used matrix material for higher performance applications. Some advantages of composite materials over conventional ones are High aspect ratio,High strength,Good insulation properties, Improved torsional stiffness and impact properties, low density. However the disadvantage is damage evolution such as fiber breakage, fiber cracking, matrix cracking and debonding that occurs before fracture.To detect such defects in composite materials non destructive testing technique can be used.The use of infra red thermography as an non destructive evaluation technique is recommended whenever the inspection is required in a quicker rate,involving no contact with the sample is required.Infrared (IR) thermography is a two-dimensional technique of temperature measurement.IR camera focuses the radiation and converts into an electronic signal and shows as thermal image [1]. IR camera transforms the thermal energy, emitted from the objects in the infrared energy band on the electromagnetic spectrum, and converts into a visible thermal image and each energy level is been represented by a different color [2]. The application of this IR technique was not only in engineering field but also in the food industry [3], irrigation [4], architectural purpose [5], environmental study [6], medical field [7] and measurements and meteorology [8].

II. EXPERIMENTAL WORK

1. Materials

The natural fibre is extracted from the plant with certain care to avoid damage. In the present experiment, initially the main stem of the banana plant is been cutted and then rolled lightly to remove the moisture. There are some impurities in the rolled fibres such as unwanted pigments, broken fibres, coating of cellulose etc. were removed, and then the fibres were cleaned and dried. The fibers were immersed in the NaoH solution for 30 min and then washed with tap water and dried. Epoxy with a density of 1.15 g/cm³ was used as a binding material.

2. Fabrication of Banana/epoxy specimens

The composite samples were prepared by combining the Banana fibers and the epoxy resin through a hand lay-up process followed by compressing the composite using compression molding. One of the main issues with Banana fiber reinforced composites that needs to be addressed is an uneven distribution of fiber [9]. Banana fibers are difficult to be separated manually during manufacturing [10]. For a total volume ratio of 60:40 per cent Banana fiber to epoxy with a thickness of 0.3 cm, 17.25 g of Banana fibers and 7.95g of epoxy were prepared.

3. Thermal imaging

IR thermal imager or IR camera is normally a camera with an IR detector. In this study the IR camera used is from IR Fluke and an active thermal imaging technique was applied to detect the defects of Banana /epoxy composites. Banana/epoxy specimens were heated in an oven at 100 ºC for 60 min. As claimed by Maldague (2001) [11], in active thermography, the surface of a sample is heated by using an external heat source and the surface is been monitored. The Banana/epoxy specimens were placed on a insulator stand so as to avoid heat dissipation through conduction from the stand. Then thermal images were recorded by the IR camera. The experiments were conducted for an emissivity of 0.92, with a room temperature of 29.9 ºC and a relative humidity of 70%.

III. RESULTS AND DISCUSSION

1. Thermography analysis

Figure 1a-c shows thermography of Banana/epoxy at 60:40 fiber loading to epoxy at a 0.3 cm, thicknesses respectively. Thermography is an image which contains thermal data presented in a contour of colour. Infrared thermal imaging technique transforms the thermal energy,which are radiating from the objects in the infrared band of the electromagnetic spectrum, into a thermographic image; each energy level is represented by a variety of colour [12]. Defects that lie below the surface will affect the heat transfer rate when thermal energy is propagating through the structures [13]. These defects or manufacturing defects are voids, excess resin, and pockets of undispersed crosslinker, misaligned fibers and also regions where the resin has been poorly wetted the fibers. It will be discussed detaily below and these thermography analyses will be verified using optical microscope.

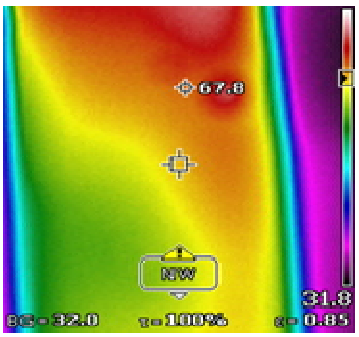

Figure (a)

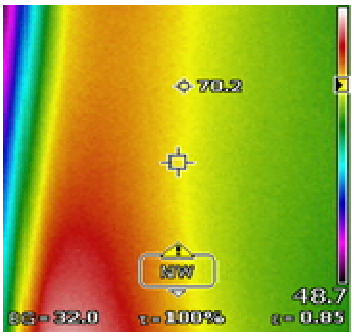

Figure (b)

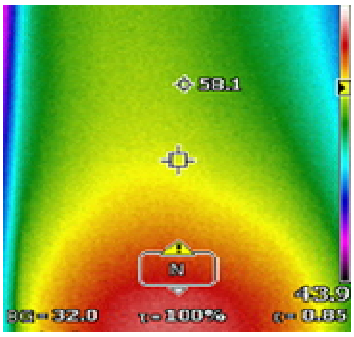

Figure (c)

Figure 1. Thermography analyses of Banana/epoxy specimen with (a) 0.1 cm , (b) 0.3 cm and (c) 0.5 cm thickness

As observed in Figure 1a, the identified defects area, has also been verified using optical microscope as shown in Figure 2. Figure 2 shows the identified defects area, which is caused by the presence of a lot of voids. Figure 1b shows the most defects area in specimen of 60:40 Banana/epoxy with 0.3 cm and Figure 3 shows the results of the optical microscope on defects area of the specimen respectively. Figure 3 shows that the defect is caused by excess resin zones. Figure 1c shows the defects area of 60:40 Banana/epoxy with 0.5 cm and the result of the defects area for this specimen while Figure 4 shows the results on the defects area of this specimen by using optical microscope respectively. Figure 4 shows that the identified defect area, which is caused by pockets of an undispersed crosslinker. The area with more defects is defined as the area which contains a lot of imperfections due to manufacturing process such as fiber orientation, less adhesion

of fiber-matrix bonding, voids and etc. and normally recorded as the highest temperature regions and represented with the red color. Specimen of Banana with thickness 0.5 cm (refer Figure 1c)which shows the area with more defects followed by the specimen with thickness 0.3 cm (refer Figure 1b) and 0.1 cm (refer Figure 1a) respectively.

2. Manufacturing defects

Generally in composites the defects will be occured during the manufacturing process by the manual construction known as 'Hand-lay-up' process. Composites will have a number of defects occured during manufacturing, which will increase the failure of the composites. Such defects include:

a) Voids
b) Excess resin zones
c) Pockets of an undispersed crosslinker
d) Misalignment of fibres [12]

Voids are defined as the air bubbles which are trapped in the resin during fabrication of composites, but voids can be caused by various factors. Voids will affect the mechanical properties indirectly by enhancing the moisture absorption [13]. Voids can also be occured due to the presence of impurities in the epoxy resins which are used for the fibre-reinforced composite fabrication, which will lead to a significant impact on the behaviour of the epoxy curing. [12].Figure 2 shows the voids in specimen of 60:40 Banana/epoxy with thickness of 0.3cm.

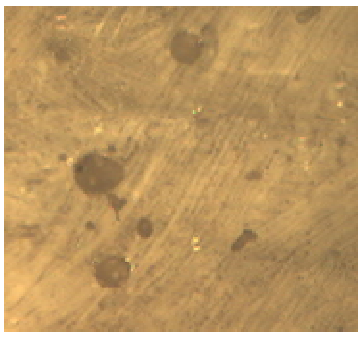

Figure 2. Voids observed in Kenaf/epoxy specimens

In research, Dewimille and Bunsell [14] discussed about the preferential cracking in the resin rich zones. It was mentioned that expansion of the resin due to the presence of water molecule which cause deformation in the excess resin zones, so greater stresses will be acting in excess resin zone and therefore more chances to fail. Figure 3 shows excess resin zone in specimen of 60:40 Banana/epoxy with thickness of 0.3 cm.

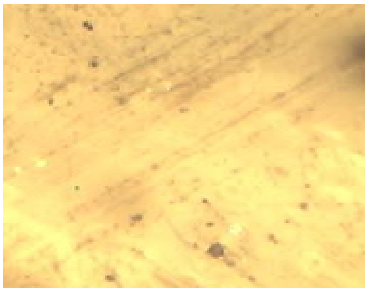

Figure 3. Resin rich zones

Pockets of an undispersed crosslinker are occured by the incomplete curing of the resin, [12]. Before analysing the properties of the composite structures, it is very important to understand the mechanical and rheological properties of the epoxy resin. Changes which are done in the adhesive due to the incomplete curing will affect the results of the adhesion test [15]. Figure 4 shows the pockets of an undispersed crosslinker in specimen of 60:40 Banana/epoxy with thickness of 0.3 cm.

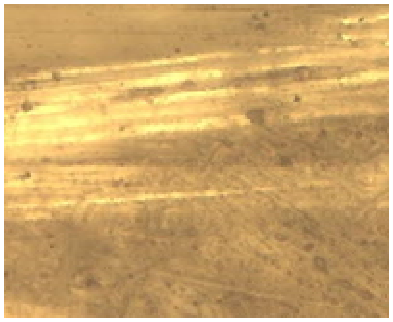

Figure 4. Pockets of undispersed crosslinker

The misalignment of fibres in the natural fibre reinforced polymer composites occurs as a result of the weak interfacial adhesion between the fibre and resin and can also be occured due to the poor dispersion of the fibre and matrix. Khalina et al.[16] studied about the mechanical properties of the injection moulded oil palm fibre reinforced composites and they reported that the fibre roughing will promote the mechanical properties such as interfacial bonding between the fibre and the resin. Figure 5 shows the misalignment of fibres specimen of 60:40 Banana/epoxy with thickness of 0.5 cm.

Figure 5. Misalignment of fibres

3. Tensile Test

Ultimate tensile strength (UTS) is known as the maximum stress that a composite can withstand when subjected to a load before fracture or breaking. UTS is also known as tensile strength (TS) or ultimate strength. It is generlly calculated by plotting typical stress versus strain curve. The UTS value is been influenced by many factors such as the temperature of the testing environment, material, and occurrence of the defects in surface.The tensile behavior of Banana fiberswith thickness 0.3 cm and 0.5 cm are presented in Figure 6a and Figure6b.The tensile strength of Banana/Epoxy with thickness 0.3 cm is around 55N/Sq mm and the tensile strength of the Banana/Epoxywith thickness 0.5 cm is around 94 N/Sq mm. The highest tensile strength has been observed in theBanana/Epoxywith thickness 0.5 cm.

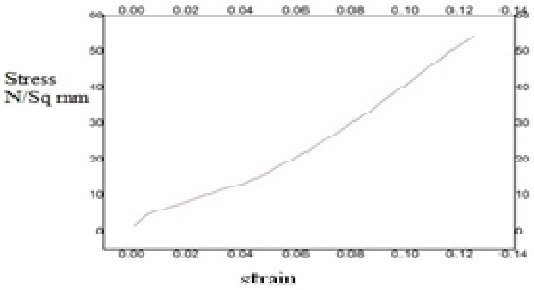

Figure (a)

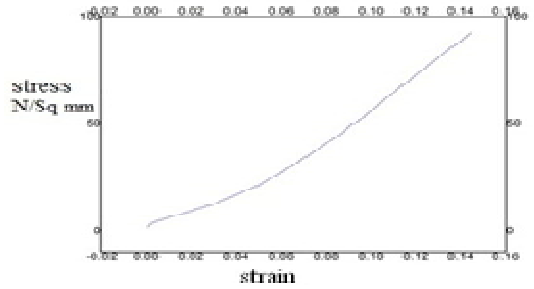

Figure (b)

Figure 6. Typical curve stress versus strain of Banana/epoxy specimen with (a) 0.3 cm and (b) 0.5 cm thickness

IV. CONCLUSION

Infrared Thermography which is a thermal imaging technique has been used as a (NDT)method to study the defects in Banana/epoxy composite materials. Thermography analysis of Banana/epoxy as shown in Figure 1a-c has been verified using the optical microscope. The defect detection accuracy of this thermography technique is around 90%. Generally defects caused by the manufacturing process such as voids, excess resin zone, pocket of an undispersed crosslinker,misalignment of fibers and regions where the resin has poorly wetted the fiber were detected by using this non-destructive testing method.

V. ACKNOWLEDGEMENT

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