Proceedings in Manufacturing Systems, Volume 9, Issue 2, 2014, 115–120 ISSN 2067-9238

FINITE ELEMENT MODELLING OF POLYMER COMPOSITES PROCESSING

Victor POPOVICI[1,*], Marinela MARINESCU [2], Larisa BUTU [3], Claudia BORDA [4], Delicia ARSENE[5]

[1)] Assoc. Prof., PhD, Materials Technology and Welding Department, Bucharest, Romania
[2)] Lecturer. PhD, Materials Technology and Welding, Bucharest Department,, Romania
[3)] Lecturer. PhD, Materials Technology and Welding, Bucharest Department,, Romania
[4)] Lecturer. PhD, Materials Technology and Welding, Bucharest Department,, Romania
[5)] Lecturer. PhD, Materials Technology and Welding, Bucharest Department,, Romania

Abstract: *This article presents finite element analysis of resin-hardener system's behaviour during composites processing. One of the main studied problems was variation of shearing force produced in the system by moving a vibrating probe between composite's layers. The fluid viscosity is defined like resistance to flowing. As follows, time variation of shearing force determined as a result of composites modeling with finite elements, describes composite system variation of viscosity depending on time. The results expected response the state of loading of the structure which has been modelling so the real conditions of its. They can provide information for a range of sizes of the same structure, as well as a range of values of the forces taken.*

Keywords: *finite element, modelling, polymer composite, shearing force, cross linking.*

1. INTRODUCTION

The development of a finite element model for soling a certain problem is done in several stages, with a binding sequence. Deployment stages and their order is the same in any program, but the subroutines can be a variety in number, structure, likely changes and optimizations. The finite element program ANSYS was used.

The steps for achieving that model are as follows: modelling geometric configuration matrix composite material (T19-36/H10-30 system) and the sensor (probe vibrating); schematization action loads; choosing the method of calculation and hence the domain of validity of the results, according to accepted assumptions; interpretation of results. Modelling geometric configuration smart composite material refers to the adoption of a system composed of elements equivalent type. Numbering of elements, nodes and degrees of freedom is arbitrary. Schematization load consists in adopting class loading (static, dynamic, etc.). Distribution and the types of tasks: distributed in volume, or per unit length inside surface and/or concentrates.

Choice of calculation method is based on modelling the configuration structure, mode of action in space and time, loads and default destination and the required accuracy of the results.

Interpretation of results is within the limits set by the assumptions adopted. The results expected response to the condition of the structure which has been shaped to fit the actual conditions. They can provide for a range of sizes of the same structures as well as to a range of intensity of the forces taken. The results are analyzed critically, stating the practical conclusions which may serve to finalize the project or improvement model used.

* Corresponding author: Institution address,
Tel.: 0040 727 442 933
E-mail addresses: *popovici_victor@yahoo.com* (V. Popovici)

Throughout the curing process of polymer composites, polymerization and chemical bonds, transforms the polymer from a viscoelastic fluid in a gel, then a rubber and finally a glassy viscoelastic material [1]. In the initial stage of curing, resin viscosity decreases due to the heat released as a result of the exothermic reaction, the heat overlapped on the outside applied to accelerate polymerization. Once initiated chemical reaction, the molecular weight increases rapidly, and chemical chains occurring bind to one another in a network with increasing molecular weight. This sudden and irreversible transformation from a viscous liquid state to inelastic gel characterized by an apparently infinite network is characterized by gelation point. Resin viscosity begins to increase due to molecular bonds. In point of gelation average molecular weight and viscosity becomes infinite, indicating a transition from a viscoelastic liquid to a viscoelastic solid. Of physically, gelation occurs when the polymer can no longer flowing, and the chemically occurs a clearly defined step of the chemical process and is dependent on the functionality, reactivity, and the stoichiometric relationship between the reactants [1].

In any manufacturing process of polymer matrix composites, processing parameters are modified to obtain the final, the most favourable terms, of mechanical properties required parts [2, 3]. To determine the inefficient processing cycles, it is necessary to make selection procedures, taking into account the large number of properties of the matrix material and fibbers respectively and processing parameters to be specified and controlled during cross linking resin. For this purpose, analytical models are a superior alternative to determine optimum processing cycles.

2. EXPERIMENTAL RESULTS

The experimental researches consisted in the monitoring of the processing of the composite material with polymer matrix using a sensor based on mechanical impedance analysis-the vibrating probe-to allow real-time measuring of the viscoelastic properties of the thermosetting polymer resins and of the composites with matrix of this type, as well as determining the processability of the composite material during treatment.

The operating concept of this sensors based on the determination of the relationship between the excitation force of the sensor as input and the response of the sensor to excitation as output, using the quantitative measurement of the vibratory force effect in the composite structures. At the interface between the vibrating probe and studied system produces a shearing motion resonating due to probe movement between the layers of composite under the action of an excitatory signal oscillating. Moving element is in this case the inserted sensor into the composite structure. By measuring the absolute peak of the probe displacement into the composite structure and the size of excitation force at resonance been possible to make estimates of the variation in complex shear modulus *G* and the viscous damping coefficient *C*. The composite material processing was permanently monitored during the sensor and data acquisition board computer (Fig. 1).

Experimental stand used for real-time monitoring of the processing of the polymer matrix composite material is composed of the following components:

Signal Generator – Brüel & Kjaer Sin tip1027 random generator – generates the excitation signal of electrodynamic exciter through power amplifier. Signal emitted from it can be harmonic with variable frequency, random narrowband or broadband. For excitation of composite structure a sinusoidal signal was used. Automatic frequency was swept over a range to three decades (1–1 000) Hz.

Power amplifier – Brüel & Kjaer tip2706 – amplifies the signal received from the low frequency signal generator which supplies electrodynamic – VEB RTF 211. Composite structure excitation is achieved by vibrating probe.

Force transducer used in this measurement system is a Brüel & Kjaer piezoelectric transducer type 8 200. The task force developed is proportional to the applied dynamic. It is mounted directly to the electrodynamic vibrator by means of threaded rods, in order to measure the strength of the composite system excitation.

The accelerometer used to measure its excitation system response composite-composite, with a harmonic force is a piezoelectric accelerometer Brüel & Kjaer type 4333, which serves as piezoelectric transducers stove.

Vibrometer – Brüel & Kjaer type 2511, placed between accelerometer piezoelectric and analyzer heterodyne, transforms the output impedance of the high value of the accelerometer in a smaller one, so convenient for measurement and analysis and to amplify the signal relatively weak over the accelerometer.

Amplifier – Brüel & Kjaer Conditioning Amplifier NEXUS, placed between the load cell and heterodyne analyzer is used for signal amplification..

Wave analyzer – Brüel & Kjaer Heterodyne Analyzer 2010 – serves to analyze the composite system response to dynamic excitation applied, achieving simultaneous excitation and response measurement to determine the dynamic characteristics of the composite system.

Level recorder – Brüel & Kjaer type 2305 – served for tracing the spectrum.

2.1. Modelling the frequency response function

In order to determine the dynamic characteristics of the composite studied, it was necessary the modelling of transfer function, which provides the relationship between the output signal, obtained by moving the vibrating probe into composite material under an exciter force produced by an electrodynamic excitatory, and material properties.

The real structure, which has an infinite number of degrees of freedom, has been replaced by the mathematical model of linear dynamic system (Fig. 2), with finite number of degrees of freedom, with constant parameters.

To simplify calculations, in all experiments the excitation force exerted on the structure and resulted acceleration were measured on the same surface. Also, for all analyzes the following approximations were made: whole ensemble of resin-fibre can be represented as a linear dynamic system; vibrating probe used to composite monitoring is moving between two layers resin; thickness of resin layer that is the one hand and other of the probe, between this and reinforcement fibre was considered to be constant; resin mass that surrounds the probe is very small and can be ignored.

Fig. 1. Experimental stand used for real-time monitoring of the processing of composites with polymeric matrix materials.

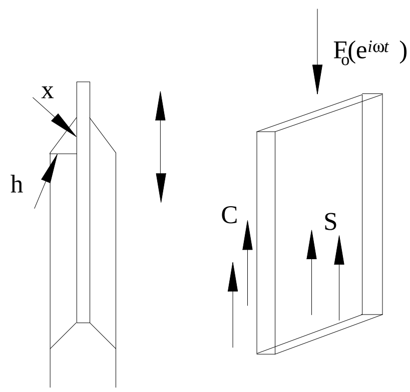

Fig. 2. The simplified model of the studied system: *C* – damping coefficient of the resin; *S* – shear force; $F_o e^{i\omega t}$ – exciter force.

Considering these approximations, the equation of motion of the system shown in Fig. 1 is:

$$M\ddot{x} + C\dot{x} + Kx = F_0 e^{i\omega t}, \quad (1)$$

where: M is the mass of the system; C – viscous damping coefficient; x – displacement; $F_o e^{i\omega t}$ – harmonic force of the excitation system. We denote

$$Kx = 2S, \text{ and } 2S = \frac{2AG}{h} x = G^* x, \quad (2)$$

where: S is the shear force onto one surface of the vibrating probe; G^* – apparent shear modulus in plan.

Then, the equation (1) becomes:

$$M\ddot{x}(t) + C\dot{x}(t) + G^* x = F_0 e^{i\omega t}. \quad (3)$$

Applying the Fourier transform equation (1), the response in frequencies function $H(\omega)$ is given by the relationship:

$$H(\omega) = \frac{\ddot{X}(\omega)}{F(\omega)} = \frac{\omega^2}{\sqrt{\left(G^* - M\omega^2\right)^2 + (C\omega)^2}}, \quad (4)$$

where: $F(\omega)$ is the input quantity – exciters force measured with an piezoelectric force transducer; $\ddot{X}(\omega)$ – system response to excitation-acceleration system, measured with piezoelectric accelerometer.

At the resonant frequency of the system it can be written:

$$G^* - M\omega^2 = 0, \quad (5)$$

$$H(\omega) = \frac{\omega}{C}. \quad (6)$$

2.2. Finite element modelling of polymer composites cross linking

The FEM model is used for the analysis of variance while the shear force produced by moving the probe vibrating composite system between layers, starting with the definition of its geometry.

In the Cartesian coordinate system, one creates a rectangular block of dimensions: L = 80 mm, W = 40 mm and h = 4 mm (Fig. 3), representing the overall resin-hardener (as approximations above), on which probe vibrators act.

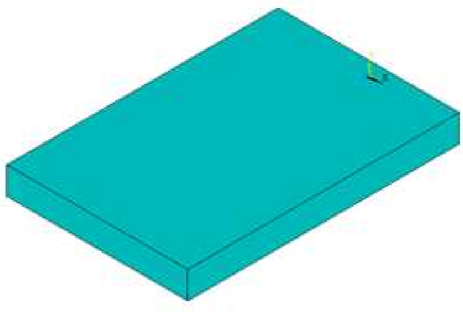

Fig. 3. Create resin-hardener assembly geometry.

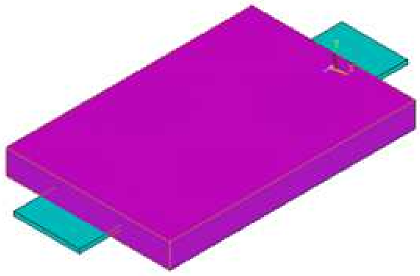

Fig. 4. Creating surface geometry "target" in moving the vibrating probe.

Since the vibrating probe is moved along the assembly, in its middle, the next step is to create surface geometry to define the "target", that is, the recess will move the vibrating probe. It also created a rectangular block with dimensions: $L1$ = 90 mm, $l1$ = 12 mm and $h1$ = 1 mm, which was subsequently dropped from the block of resin-hardener (Fig. 4). Also, in this stage of creation, the model geometry has been completed with the vibrating probe as a block having sizes: $L2$ = 60 mm, $l2$ = 12 mm and $h2$ = 1 mm.

Since the model is symmetric, and given the complexity of the model that requires quite large computational resources, we found that a quarter of the geometry is sufficient to simulate the problem.

The type of analysis used in solving this problem is non-linear quasi-static. To ensure the convergence of the solution, it was used the automatic conversion routine. Analyses were performed on several times for different values of the coefficient of friction between the probe and the vibrating composite material and at different values of resonant frequency, the purpose being to determine the stress state of the material induced by the movement of the probe, and determination of the variation of the shear force reaction force probe displacement composite system between its laminate, which produces shear displacement of material [4, 5].

The finite element analysis of the variation in time of the shear force produced in the composite system by moving the vibrating probe between layers was performed using the ANSYS software [6]. The "surface on surface" contact model was used in this analysis, to form a contact pair. This model uses a surface "target" and a surface "contact". Considering that friction is between a rigid (vibrating probe) and a viscous surface, which changes their viscosity over time (resin-hardener system), one opted for a model "flexible-rigid", and the most appropriate to simulate real working conditions.

Figures 5 and 6 show the geometry of the pattern studied and the meshing. To make the whole geometry meshing VISCO89 element for resin and SOLID 45 element for probe was used (Fig. 6) [6].

In order to comply with physical model developed, the constraints are applied inside the pattern. Due to the complexity of the studied phenomenon, to facilitate the computations, the model was divided into four equal parts. Constraints were applied on surfaces that have resulted from this division and on lateral surfaces of the composite (Fig. 7.). Lateral surfaces were encased according the conditions in which experiments were conducted.

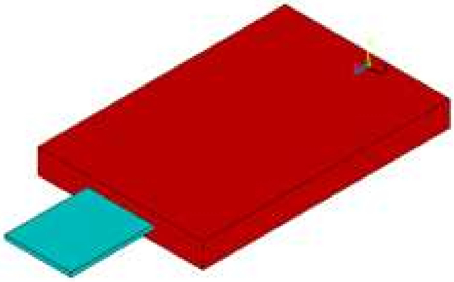

Fig. 5. Resin-hardener-vibrating probe geometry.

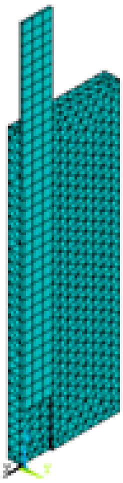

Fig. 6. The finite element meshing of studied system.

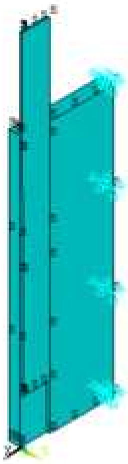

Fig. 7. Applying the constraints on contact surfaces and exterior surfaces.

In order to analyze the problem of interference results, load displacement was zero in the first step of the application. In the second stage, on the "master" node, and implicitly on the all connected nodes associated with it, have been applied displacement values ranging between ±0.1 and ±1 mm. These values simulate real movement in the composite material of vibrating probe. Variation of the shear force was determined in the system as the reaction force to the displacement sensor. Before viewing all the results of analyzes the geometry was rebuilt (Fig. 8.). Results were obtained for the whole studied assembly.

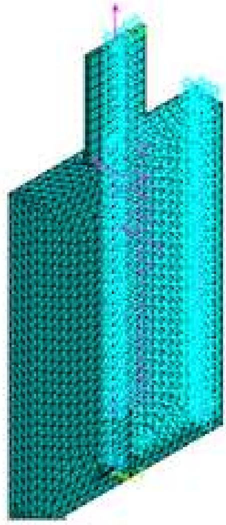

Fig. 8. Geometry assembly rebuild.

To simulate the reticulation process of the resin, the friction coefficient between resin-hardener system and vibrating probe was modified for different analyzes, taking into account the properties of resin-hardener system. At the moment of the exothermic peak, the coefficient of friction decreases from baseline with decreasing viscosity of the system, and the nit is increased as reticulation process progresses.

3. RESULTS

The quasi-static nonlinear analysis used in solving this problem. To ensure convergence solution has been used automatic conversion routine to the next time frame on the analyzed.

Several analyzes have been made using different values of the friction coefficient, the ultimate goal being to determine the variation of reaction force produced in resin-hardener system by the movement of the vibrating probe at different excitation frequencies and different time intervals.

Finite element modelling program ANSYS supports three contact models "node node", "surface area" and "node surface". For this analysis was used to model contact "surface area", which uses a surface "target" and an area of „contact" to form a contact pair.

Contact problems have two significant problems: the general contact region is not known prior to the analysis and most contact problems take into account the friction between the surfaces (in this case the friction between the vibrating probe and the resin-hardener).

Since friction is between a rigid (vibrating probe) and a sticky surface that change its viscosity over time (resin-hardener system), I opted for a model "flexible-rigid", the most appropriate for to simulate real working conditions.

Figures 9–14 show the variation curves for shear force for different values of the coefficient of friction and the resonance frequency.

In Figs 15–18 the tension produced resin-hardener system to probe vibrating movement is presented.

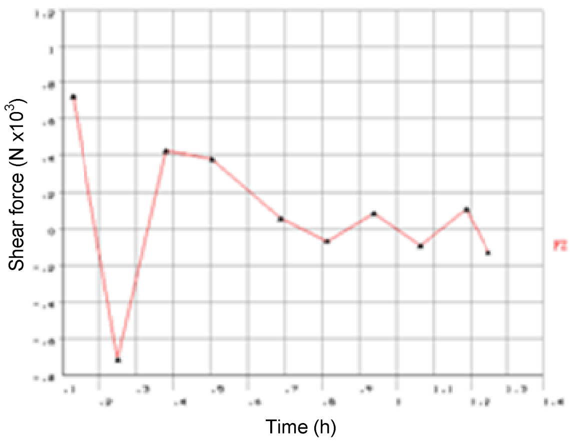

Fig. 9. Shear force [N×10^3] versus time [h] for μ = 0.03 and *f* = 5 Hz.

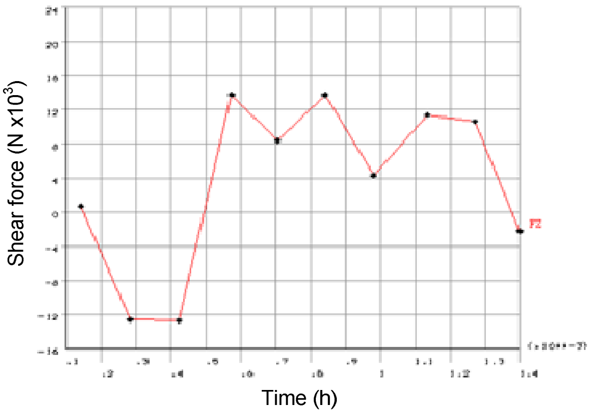

Fig. 10. Shear force [N×10^3] according time [h] for μ = 0.04 and *f* = 10 [Hz].

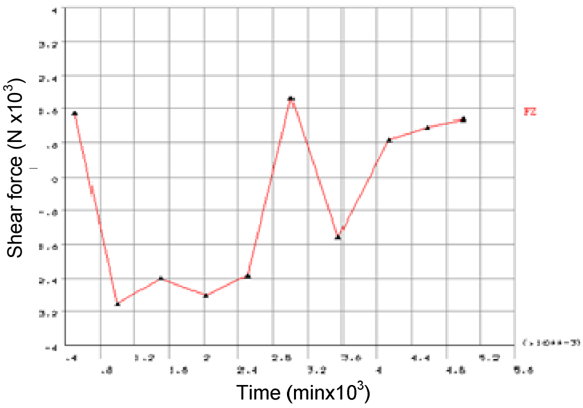

Fig. 11. Changes in shear force [N×10^3] time [min × 10^3] for μ = 0.05 and *f* = 12 Hz.

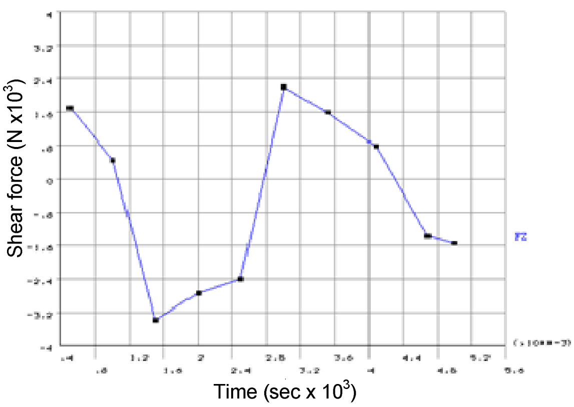

Fig. 12. Changes in shear force [N×103] agains time [sec. ×103] for μ = 0.06 and *f* = 14 Hz.

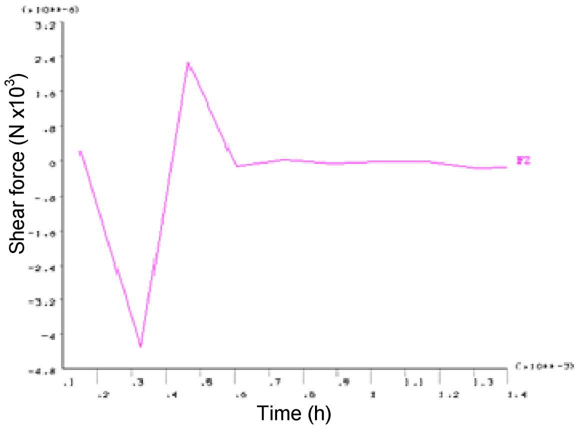

Fig. 13. Shear force [N×10^3] according time [h] for μ = 0.07and *f* =16.4 Hz.

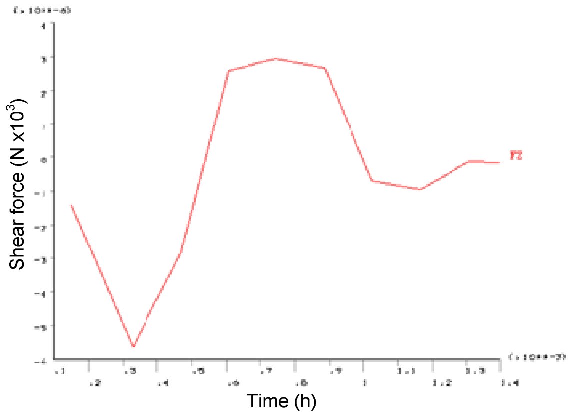

Fig. 14. Shear force [N×10^3] according time [h] for μ = 0.08 and *f* = 19.2 Hz.

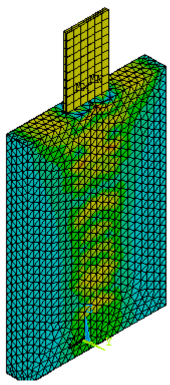

Fig. 15. Tension produced resin-hardener system to the excitation frequency 15 Hz.

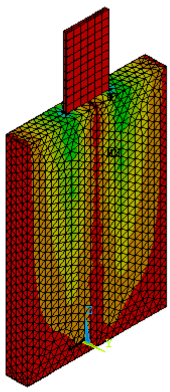

Fig. 16. Tension produced resin-hardener system excitation frequency 18 Hz.

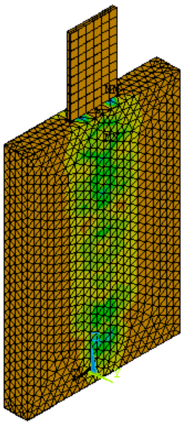

Fig. 17. Tension produced resin-hardener system excitation frequency of 10 Hz.

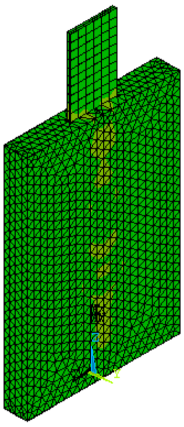

Fig. 18. Tension produced resin-hardener system excitation frequency of 5 Hz.

4. CONCUSIONS

The model created by finite element method simulates the movement sensor in the composite material with dimensions, shapes and material properties corresponding to those used to build the system studied experimentally.

Defined in terms of geometric model, assigning the geometry properties of material (resin-hardener separate system for vibrating probe) according to data provided by the manufacturer, then the meshing operation was performed after which the resulting number of elements and nodes to be extracted the calculations.

The analysis was applied to nonlinear quasi-static in order to determine the force curve of the composite system response that produced shear displacement sensor system for different values of the coefficient of friction between the probe and the resin-hardener system to different excitation frequencies and different periods of time.

Due to the large number of properties of the matrix material, respectively of the fibres, depending of the processing parameters to be specified and controlled during reticulation of the resin, the optimization of manufacturing conditions of an intelligent composite material with polymeric matrix using experimental analysis is often expensive and takes a long time. For this purpose, an alternative is analytical model for determining optimal processing cycles and finite element analysis representing an important advantage in terms of time savings.

It was found that for all values of the friction coefficient (0.03–0.05), corresponding to a low viscosity of the resin-hardener system, the shear force produced in the system has values inside the interval $(0.6–2.0)\times10^3$ N. At the moment of the exothermic peak, the friction coefficient decreases from baseline at the same time with decrease in viscosity of the system, and after this it increases as reticulation process progresses. For higher values of the friction coefficient (0.06–0.08), which define progressive reticulation system, the shear force has values in the range $(2.0–3.2)\times10^3$ N.

REFERENCES

[1] M. Ya. and S.G. Kulichikhin, *Rheokinetics of Curing*, Advances in Polymer Science, 101, 1991, pp. 217–257.

[2] V. Mantic, *athematical Methods and Models in Composites*, Ed. World Scientific Co. Pte., Dec. 2013.

[3] W.H. Lee, *Computer Simulation of Shaped Charge Problem*, Ed. World Scientific Publishing Co. Pte. Ltd., May 2006.

[4] P. Krysl, *A Pragmatic Introduction to the Finite Element Method for Thermal and Stress Analysis*, Ed. World Scientific Publishing Co. Pte. Ltd., Oct 2006.

[5] W. Smith, S. Qiao P., Chen F., *Experimental Investigation on FRP to Timber Bonded Interfaces*, Journal of Composites for Construction, Vol 18, No.3, June 2014

[6] *** Ansys Tutorial.