Particle Swarm Optimization Application for Timber Connection with Glass Fiber-Reinforced Polymer (GFRP) and Non-GFRP

Marina Yusoff, Dzul Fazwan Othman, Rohana Hassan and Anizahyati Alisibramulisi

Abstract Timber connection is one of the important aspects that need to be evaluated in construction and manufacturing. The end product produced from these sectors depends on the strength of the timber connection especially in building constructions. A lot of laboratory experiments to measure the strength of timber connection were done before proceeding with the transformation process of a product. However, these experiments require high cost and time-consuming. In addressing these issues, there is an alternative mean that can be applied to predict the strength of timber connection to overcome those problems. This paper addresses on the employment of particle swarm optimization (PSO) in a simulated timber connection for tensile test with and without glass fiber-reinforced polymer (GFRP). Data from laboratory experiment of tensile test of tropical timber were used. The PSO potentially can adapt the behavior of the timber and predict the maximum weight that can be supported by the timber connection. The findings are acceptable which obtained 99.39 % accuracy for GFRP joints and 95.34 % accuracy for non-GFRP joint. By using population size of 20, it has shown that PSO provides good results and has capability to predict the timber joint strength. Results show that by combining the glass fiber-reinforced polymer (GFRP) sheet, the timber joint gives better strength than timber joint without GFRP. Thus, the outcome of PSO application would encourage the engineer or related construction fields to predict the timber joint strength with various fiber-reinforced polymer or other composite material.

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M. Yusoff et al. (eds.), *InCIEC 2015*, DOI 10.1007/978-981-10-0155-0_10

Keywords Glass fiber-reinforced polymer · Particle swarm optimization · Timber connection · Tensile test

1 Introduction

Timber has been used for many centuries for constructions and still popular as building materials. Timber is the wood of growing trees suitable for structural uses in building construction. Timber gives benefits in terms of cost, obtainability and strength, thus timber is widely used until now. Malaysia is not excluded from being one of the timber suppliers in this world. According to MIDA (2012), Malaysia has invested in wood-based industry [1]. The timber industry itself contributes about RM20 billion to the Malaysia exports a year and some RM13 billion each year to the domestic market [2]. There are two types of timber which are softwood and hardwood. The tropical in forest in Malaysia usually consists of hardwood such as Merpauh, Keruing, and Jelutong. Each hardwood timber has different specification in terms of strength, treatability, and physical properties.

A laboratory experiment needs to be conducted for determining the strength of timber joint [3]. The experiment requires a set of specialized tools and machine for instance by using universal testing machine. There are several ways to test the strength of the timber joint, such as tensile test, bending stress test, and compression test. However, the experiment requires a large number of timbers with a various types of species to determine the strength of timber joint. Besides the timber, the experiments require some composite material such as bolt, adhesive glue, and fiber-reinforced polymer in order to make a joint possible. Thus, the laboratory experiments require a lot of cost and it is time-consuming.

This paper addresses the use of computational method to help reducing cost and time of laboratory experiment. Previously, there are various computational techniques that have potential to give results a little bit same as laboratory experiment such as partcle swarm optimization (PSO) [4, 5] genetic algorithm, and Monte Carlo method [6]. A study by Yusoff et al. [5] simulates a laboratory experiment on timber joints which can assist the traditional experimental analysis with the finding of the possible end distance in a single shear timber joint using PSO. The authors further-mentioned fitness function of PSO in solving this problem is determined based on findings from datasets of laboratory experiment. Yusoff et al. [5] has suggested that a better computational result would be possible to obtain by the employment of the PSO technique on different types of timber, joints, and composites.

2 Related Work

Tensile test is one of common manual techniques that commonly use to predict strength of a timber connection. This technique requires special machine called universal testing machine in order to run the experiment. This machine is considered universal because it can be used for compression and bending test also. Figure 1 shows the universal testing machine.

Tensile test is based on tension capacity or pullout capacity. According to Favilla [7], tensile test is necessary to understand the properties of different materials and study the behavior of the material under certain load capacity. He also stated that the data from the test can be used to determine valuable material properties as such ultimate tensile strength, modulus of elasticity, and yield strength. The example of test procedure is from Shafenzi [8] as shown in Fig. 2.

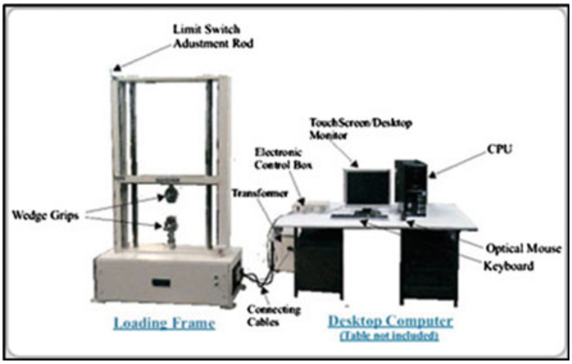


Fig. 1 Universal testing machine

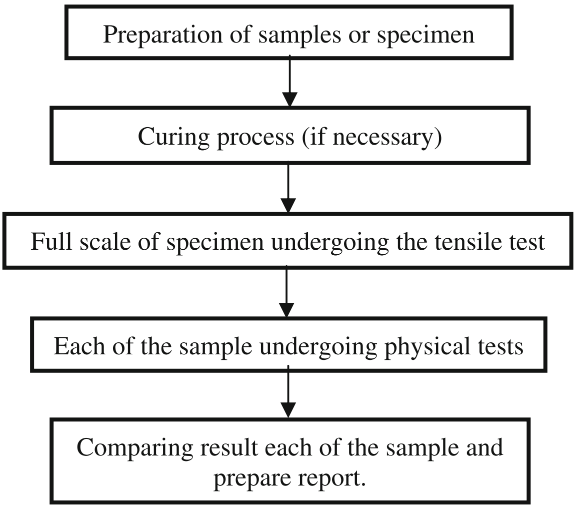
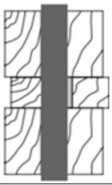
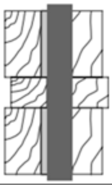
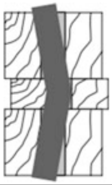
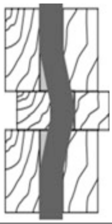
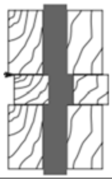


Fig. 2 Flowchart of procedure in tensile test

Table 1 Failure mode

Illustration	Failure mode	Description
	I_m	Dowel bearing strength of the main member (tenon) is exceeded. The tenon wood crushes
	I_s	Uniform bearing by the dowel (peg) exceeds the dowel bearing strength of the mortise sidewalls. The mortise sidewall wood crushes
	III_s	A hinge point occurs in the tenon near each shear plane and the peg ruptures or bends.
	IV	The peg bends with limited rotation, forming two hinges near each shear plane in the mortise sidewalls and one hinge in the center of the tenon
	V	The peg fails in cross-grain shear at each side of tenon (double shear failure)

Source Judd et al. [10]

Tensile test typically involves with the process of pulling out the specimen with certain load until the specimen reaches failure mode. Failure mode is a condition which happens when the specimen is no longer can sustain the load capacity. According to Hassan et al. [9], the failure mode is based on European Yield Model (EYM). The description of each mode in failure mode is shown in Table 1.

3 Particle Swarm Optimization

PSO was developed in 1995 by Kennedy and Eberhart based on birds flocking and fish schooling's social behavior [11, 12]. There are vast of particle swarm optimization design in solving a problem. This paper addresses the use of canonical PSO algorithm. Figure 3 shows the flowchart of the PSO algorithm from the first step until the optimal load capacity is attained. From the Fig. 4, the first step is initializing population with random particle position (x) and its velocity (v). The number of particles depends on the population size. The random particle position (x) is based on range of selected deformation or displacement data. The initial velocity range is between −1.0 and 1.0. After the initialization process, each particle will be evaluated based on its own fitness. If the particle I is the best among all existing particles then it was being declared as initial pBest and gBest. Then, the particle position and velocity will be updated. The new particle position and velocity, will be evaluated again based on its fitness and compete among them to get the pBest. The pbest will compete with the previous gBest. If the pBest win, it will become new gBest. This process will continue until reached maximum iteration. Finally, the current gBest is declared as optimal load capacity. Two types on inertia weight which is constant or fixed weight and ranged weight. The constant weight value is 0.9 that was taken from research by Bhattacharya and Samanta [13]. The ranged weight value is from −1.0 to 1.0 based on the suggestion of research in Yusoff et al. [5, 14].

4 Data Acquisition and Experimental Setup

4.1 Datasets Preparation

The timber and composite material connections were tested to make a comparison between the connection using GFRP material and without the GFRP material. The types of timber joints that have been tested are single shear and double shear. The strengthening material used for jointing the timber was the GFRP wrapper with 250 mm × 500 mm dimension. The timber has been fastened with 1.5 times diameter (1.5D) end distance where the diameter of the dowel is 20.6 mm. The single shear connection has been tested using Bintangor species while double shear connections were tested using Kapur species. Basically, the raw data from the actual experiment will be preprocessed to identify the equation of the fitness function. After that, the tabulated graph will be fitted with polynomial curve fitting tools. The polynomial curve fitting can fit the graph from 4th degree until 10th degree. A polynomial equation is produced to be used as fitness function in PSO algorithm. Some example of the preprocessed data is illustrated in Figs. 4 and 5.

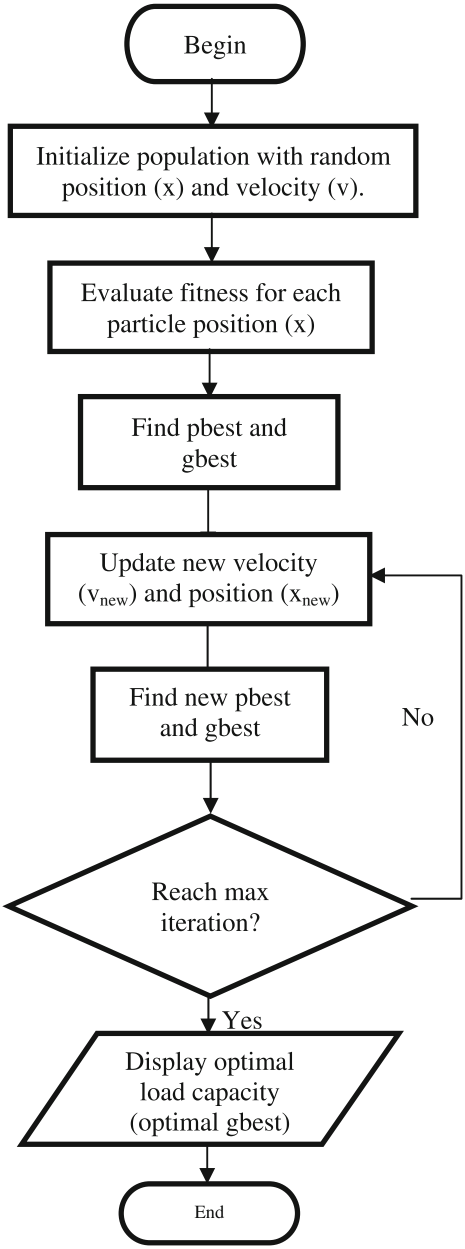


Fig. 3 Flowchart of particle swarm optimization

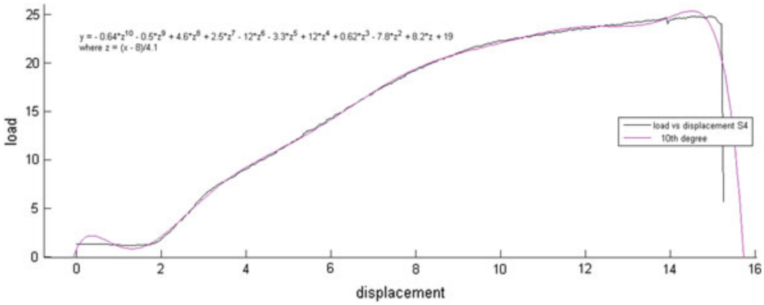


Fig. 4 Graph of half lap joint without GFRP

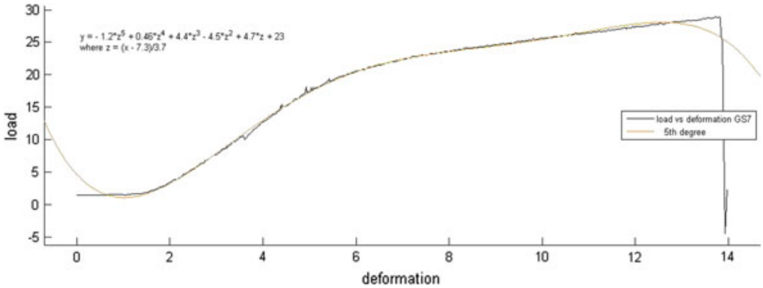


Fig. 5 Graph of half lap joint with GFRP

4.2 PSO Parameter Setting

PSO has several parameters to be initialized such as velocity, constant value of coefficient, inertia weight, and the number of random population. Table 2 shows parameter values used for predicting the timber joint.

Table 2 Parameter setting

Parameter	Values
Population size	10, 20, 30
Iteration size	5 and 10
Velocity, V	−1.0 to 1.0, −2.0 to 2.0, and −3.0 to 3.0
Inertia weight, W	0.9 and −1.0 to 1.0
Constant coefficient, C1 and C2	2.0

The system was tested using ten samples of displacement data from actual laboratory experiment. The data is tested one by one in order to get the most optimal load capacity. The best result from each data sample is selected based on certain criteria. The criteria should be followed sequentially in order to get only one best result from each data sample. The criteria are described below.

i. Select the highest load capacity (kN).
ii. If there is more than one load with higher value, choose the load that has highest displacement value (mm).
iii. If there is more than one load with higher displacement value, choose the load that is gained from lowest population size value. This is for measuring the performance of the system

5 Findings and Discussion

The most optimal load capacity that has been achieved by the system is 28.1469 kN. The best result from each data sample is highlighted with bold font. From the result obtained, most data samples attained highest optimal load capacity at 20.2777 kN except for data sample 10 which only achieved 20.2776 kN. The best result from each data sample is highlighted with bold font. Table 3 shows compilation of best optimal load for each data sample.

Based on information displayed from Table 3, the maximum displacement a timber joint without GFRP can sustain until reaching optimal load of 20.2777 kN is 11.8477 mm. The result seems to get 95.34 % accuracy compared to the actual laboratory experiment result. The system is capable to get optimal load in population size of 30, iteration of 10, inertia weight from −1.0 to 1.0, and velocity from −1.0 to 1.0.

Table 3 Compilation of optimal load for timber joint without GFRP

Data sample	Population	Iteration	Weight	Velocity	Best displacement (mm)	Optimal load (kN)
1	20	10	0.9	−1.0 to 1.0	11.8463	20.2777
2	30	10	−1.0 to 1.0	−2.0 to 2.0	11.8470	20.2777
3	20	5	0.9	−1.0 to 1.0	11.8469	20.2777
4	30	5	0.9	−3.0 to 3.0	11.8470	20.2777
5	20	10	−1.0 to 1.0	−3.0 to 3.0	11.8432	20.2777
6	**30**	**10**	**−1.0 to 1.0**	**−1.0 to 1.0**	**11.8477**	**20.2777**
7	20	5	−1.0 to 1.0	−3.0 to 3.0	11.8458	20.2777
8	30	5	−1.0 to 1.0	−3.0 to 3.0	11.8428	20.2777
9	20	5	0.9	−3.0 to 3.0	11.8446	20.2777
10	30	10	0.9	−2.0 to 2.0	11.8422	20.2776

Table 4 Compilation of optimal load for timber joint with GFRP

Data sample	Population	Iteration	Weight	Velocity	Best deformation (mm)	Optimal load (kN)
1	20	10	−1.0 to 1.0	−2.0 to 2.0	12.4792	28.1469
2	20	5	0.9	−2.0 to 2.0	12.4796	28.1469
3	20	10	0.9	−2.0 to 2.0	12.4784	28.1469
4	30	10	−1.0 to 1.0	−1.0 to 1.0	12.4785	28.1469
5	20	10	0.9	−3.0 to 3.0	12.4775	28.1469
6	20	10	0.9	−3.0 to 3.0	12.4751	28.1469
7	20	10	−1.0 to 1.0	−1.0 to 1.0	12.4760	28.1469
8	30	10	−1.0 to 1.0	−1.0 to 1.0	12.4792	28.1469
9	**20**	**10**	**0.9**	**−3.0 to 3.0**	**12.4797**	**28.1469**
10	30	5	−1.0 to 1.0	−1.0 to 1.0	12.4788	28.1469

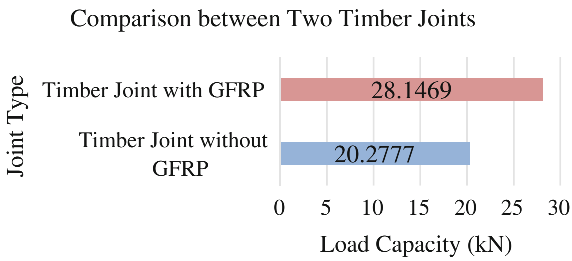


Fig. 6 Comparison between two timber joints based on load capacity

Based on information indicated from Table 4, the maximum deformation a timber joint with GFRP can sustain until reaching optimal load of 28.1469 kN is 12.4797 mm. The result seems to get 99.39 % accuracy compared to the actual laboratory experiment result. The system is capable to get optimal load in population size of 20, iteration of 10, inertia weight of 0.9, and velocity value from −3.0 to 3.0.

The result obtained from the system testing shows that by applying glass fiber-reinforced polymer (GFRP), the timber joints tend to increase the load capacity which can be sustained. Besides that, the timber joint with GFRP also tends to get optimal result quicker that non-GFRP timber joint since most GFRP timber joint samples get optimal load capacity in population size of 20 compared to non-GFRP timber joint. Figure 6 shows a comparison between two types of timber joints based on optimal load capacity that has been obtained by the system.

6 Conclusion

This project was successfully developed to primarily offer an alternative way of predicting the strength of timber joints with the use of artificial intelligence techniques, namely PSO. The outcome of this project is able to assist the people that involved in various sectors, such as designer, engineer, architect, and contractor to find the optimal structural capacity of the strength of timber joint. The system is expected to help in minimizing time and cost of the conventional timber experiment.

Acknowledgements The authors would like to thank Faculty of Computer and Mathematical Sciences, Faculty of Civil Engineering, University Teknologi MARA and Institute for Infrastructure Engineering and Sustainable Management (IIESM) in establishing this research.

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