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The Implementation of Statistical Inference to Study the Bending Strength of Sustainable Hybrid Sandwich Panel Composite

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Abstract. The study reported here involves the evaluation of the ultimate bending stress (bending strength) of hybrid sandwich panels using a simple comparative statistical analysis. Four sets of beam were tested with each set consisting of modified beams (MB) and unmodified beam (UB) samples. A total of 42 beam samples were tested using 3 point bending followed by statistical inference analysis using a t-test. The results show that the introduction of an intermediate layer has a significant effect on increasing the bending strength of the new hybrid sandwich panel composite.

Introduction

Sandwich panels have become an attractive option in the construction industry in recent years due to their many advantages, which include a high strength to weight ratio. More recently, new hybrid sandwich panel composites have been proposed by Mamalis [1] with the introduction of intermediate layers between the two conventional sandwich materials (skin and core). In the study reported in this paper glass fibre epoxy composite and wood were utilised as intermediate layers. The face layers used were aluminium, steel and glass fibre epoxy composite. It was found that the new design improved the bending behaviour of the sandwich panel and reduced the cost. However, a cost-effective criterion was employed as the main parameter during the experimental work. The size of samples tested, including their thickness, was uncontrolled. It was thus essential to employ different approach to further investigate this new hybrid sandwich panel concept. In this work, sustainable based materials were employed as the intermediate layer and the results were analysed using statistical approach.

Much research has been undertaken on composite sandwich panels. Most of the research however, only presented test results descriptively without fully testing the research hypothesis using statistical inference. It is not surprising then that the results of many published papers differ widely. In many cases the investigators were attempting to draw certain inferences, or make decisions regarding an isolated hypothesis, specific to the situation being studied. Hicks stated that statistical inference refers to the process of inferring characteristics about a population, from a sample drawn from that population [2], or a collection of tools for making the best possible decisions in the face of uncertainty [3]. This process usually involves testing a hypothesis using appropriate rules, with the outcome that the hypothesis is either accepted or rejected.

In order to analyse the results of experiment in a statistical framework, a statistically design should be employed while the objectives are being formulated and before the test is run. Montgomery defined this process as a statistical design of experiments which refers to the process of planning the experiment so that the appropriate data can be collected and analysed by statistical methods resulting in valid and objective conclusions [4]. A well-designed experiment is extremely important because the results and conclusions that can be drawn from the experiment depend on the way data is derived. In addition, Giesbrecht explained that the goals of statistical experimental design are to provide means that to ensure the experiment will be capable of obtaining answers to the research questions addressed. It will also provide the information as efficiently as possible using the available resources and constraints [5].

The statistical experimental design employed for this study was a simple comparative analysis, which is specifically designed to answer the question of significance between experimental variables.

The objective of this kind of experimental design is to compare two different treatments or the effect of a treatment. This paper presents the results of an experimental study statistically designed using a simple comparative approach and analysed using statistical inference to answer the research question: does the introduction of an intermediate layer (the treatment) give any improvement to the bending strength of a sandwich panel?

Experimental Program

True experimental design is regarded as the most accurate form of experimental research that tries to prove or disprove a research hypothesis mathematically using statistical analysis [6]. The distinctive of this research method is the presence of variables and a viable control group and the sample groups must be assigned randomly. Kuehl [7] explained that the control treatment is a necessary benchmark treatment to evaluate the effectiveness of experimental treatments. A control treatment may represent the factor with no treatment or a standar practice to which the experimental method may be compared. In the current research, a group of sandwich beam samples containing an intermediate layer, which were called modified beams (MB), were considered being treated. A control group of samples, without any intermediate layer were defined as unmodified beams (UB) and untreated. This experiment was carried out in four different categories based on the type of core material used and two levels (a=2) of factor (being size). For the first two categories, large samples were replicated 6 times, and small samples were replicated 5 times. A total of 42 samples were tested in this experiment.

The sandwich panels were made in accordance with ASTM C393-00 standard [8]. The large samples were 312.5 x 25 x 12.5 mm and the small samples were 250 x 20 x 10 mm, with gauge length of 250 and 200 mm respectively. A 3-mm thickness of aluminium was used as the face sheet for all samples. For the large samples, balsa wood and expanded polystyrene (EPS) were used as the core and plywood as intermediate layer. For small samples, EPS and polyethylene were employed as core material and balsa wood as intermediate layer. The thicknesses of samples were kept constant at 12.5 mm for large beam samples and 10 mm for small beams. The overall length of beam is 25 times of thickness (t), 20t for simply supported span and 2t for the width. All the components were bonded together using the epoxy resin, Kinetix R246Tx thixotropic with Kinetix H160 hardener. All specimens were tested using simple 3 point bending as per ASTM C 393-00 using a MTS Alliance RT/10 with a maximum capacity of 10 kN.

Framework for Analysis

As this paper focuses on statistical analysis, the framework analysis presented here is related to the simple comparative analysis. The respons variable used is the bending strength of sandwich panel. The procedure proposed by Montgomery [9] was used to analysis the result of this work. The procedure begins with describing the model for this statistical analysis, which is

$$y_{ij} = \mu_i + \begin{cases} i = 1, 2, \dots, a \\ j = 1,2, \dots, n_i \end{cases} \tag{1}$$

where,
y_{ij} : response of the *ij*th observation
μ_i : mean of the response at the *i*th factor level
ϵ_{ij} : random variable associated with *ij*th observation

The hypotheses for this statistical analysis are

$H_0: \mu_1 = \mu_2$
$H_1: \mu_1 \neq \mu_2$

Supposed that the variances is equal, then the appropriate test statistic to use for comparing two treatment means in the completely randomized design is

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2 - 0}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \tag{2}$$

where,
$\bar{y}_1$ and $\bar{y}_2$: the sample means
n_1 and n_2 : the sample sizes

S_p is computed from $S_p{}^2$, which is an estimate of the common variance

$$S_p{}^2 = \frac{(n_1 - 1)s_1{}^2 + (n_2 - 1)s_2{}^2}{n_1 + n_2 - 2} \tag{3}$$

where,
$s_1{}^2$and $s_2{}^2$: the two individual sample variances

To determine whether to reject H_0 or not, the value of t_0 would be compared with the t value obtained from the t distribution table. This test procedure is usually called the Two-Sample *t*-test. The H_0 will be rejected when the value of t_0 is

$$|t_0| > t_{\alpha/2,n_1+n_2-2} \tag{4}$$

Result and Discussion

Minitab-15 Software was used to analyse the result of experiments. As already mentioned earlier, this experiment is specifically designed to answer the question of how significant the difference between two treatments. Typically one is a control level and the other is the treatment level. The results of experiment are summaried in Table 1 which shows the bending strength of all four different categories of samples. The parameter of interest is that whether the mean of bending strength of modified and unmodified beam is significantly different. The coefficient of variation values provide some indication whether the set of samples consitutent a lot. Typically a value of above 20% is considered excessive.

Table 1. Bending strength (Mpa) of modified and unmodified sandwich panel beam samples for various categories

Sample	Large beam with Balsa core		Large beam with Polystyrene core		Small beam with Polystyrene core		Small beam with Polyethylene core	
	MB	UB	MB	UB	MB	UB	MB	UB
1	113.94	62.66	22.34	10.12	32.92	10.61	10.08	2.29
2	107.80	76.38	21.30	8.66	43.54	18.36	10.43	2.83
3	117.41	43.98	23.81	9.99	36.36	10.10	7.99	2.78
4	105.83	56.56	21.30	6.46	44.64		9.53	3.21
5	127.67	62.18	17.86	6.65	33.62		12.82	3.25
6	105.36	51.20	19.08	10.78				
Average	113.00	58.83	20.95	8.78	38.22	13.02	10.17	2.87
Std Dev.	8.63	11.12	2.16	1.85	5.53	4.63	1.75	0.39
Coeff Var.	0.076	0.189	0.103	0.210	0.145	0.356	0.172	0.136

A simple comparative analysis using Two-Sample *t*-test was carried out for all categories. The results of the first category; large beam with balsa core is presented in the Table 2. The result script gives some informations, but the important things for statistical inference are the T-value and P-value. As it can be seen from the Table 2, the T-value of the test is 9.43, while the P-value is 0. The rule for making an inference or decision in this typical analysis is based on Equation 4: the H_0 hypothesis should be rejected when the T-value is higher than the T_α, which is obtained using t-distributions available in statistic books. With the level significance of 0.05 and the value of degree of freedom (DF) = 10, the above table gives the critical value, T_α=2.228. As T-value = 9.43 exceeds the critical value, so the null hypotheis should be rejected at this level (0.05) which means that the bending stress of modified sandwich panel with intermediate layer is significantly different (higher) than the unmodified panel.

Table 2. Computer output using Minitab 15 software for the Two-Sample *t*-test

```
Two-Sample T-Test and CI: Modified Beam (MB), Unmodified Beam (UB)
Two-sample T for Modified Beam (MB) vs Unmodified Beam (UB)
                     N    Mean  StDev  SE Mean
Modified Beam (MB)   6  113.00   8.63      3.5
Unmodified Beam (UB) 6    58.8   11.1      4.5
Difference = mu (Modified Beam (MB)) - mu (Unmodified Beam (UB))
Estimate for difference :  54.17
95% CI for difference   :  (41.37, 66.98)
T-Test of difference = 0 (vs not =): T-Value = 9.43  P-Value = 0.000  DF = 10
Both use Pooled StDev = 9.9506
```

Table 3. Summary of Two-Sample *t*-test results

No	Categories	Minitab Analysis			
		T-value	P-Value	DF	$t_{\alpha/2,\, n_1+n_2-2}$
1	Balsa core (Large)	9.43	0.000	10	2.228
2	Polystyrene core (Large)	10.46	0.000	10	2.228
3	Polystyrene core (Small)	6.58	0.001	6	2.447
4	Polyethylene core (Small)	9.10	0.000	8	2.306

The results of the analysis for all sample categories are presented in Table 3. In order to provide a T-value based t-distribution table (T_α), the degree of fredoom should be used together with the choosen significancy level (α). In this analysis it was decided to use the significancy level of 95% (α = 0.05). It is clearly demonstrated in the above table that the value of calculated T-value exceeds the value of T_α which means that we accept the alternative hypothesis (H_1) and reject the H_0. The alternative hypothesis which states that the average values of the treatment is different. In other words, the bending strength of the unmodified sandwich panels is significantly lower than that of the modified sandwich panels.

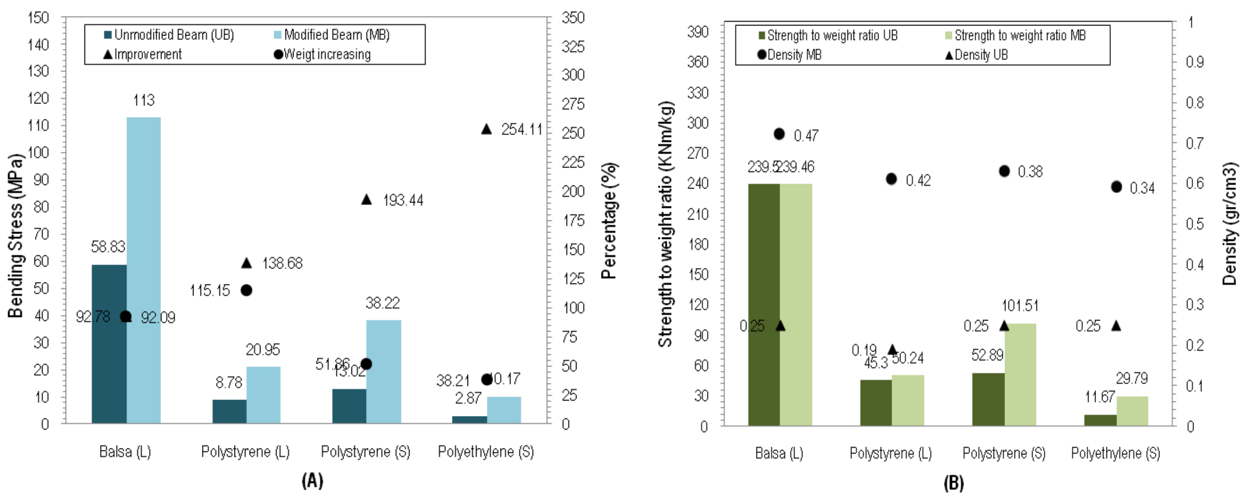

Fig 1. Bending stress (Mpa) and improvement (%) of sandwich panel beam (A). Strength to weight ratio (KNm/kg) and density (gr/cm^3) of sandwich panel beam (B)

As statistical inference terminology is not often used in composite engineering research, a clear illustration using statistical descriptive in the form of column graph is also presented here. Fig 1(A) clearly shows the significant enhancement of bending stress by introducing the intermediate layer. The bending stress of all modified beam (MB) were notably higher than the unmodified beam (UB). The improvement ranges from 90% to around 250%, dependent on the type of the core material used. The lower strengh the core material, the higher the improvement gained by introducing intermediate layer. When a low density (low strength) core material used such as polyethylene and polystyrene, early failure occurs due to localised compression. The introduction of intermediate layer results in improved bending strength but is not warrented when a very low core material such as polyethylene used as the core. The graph shows that the maximum average bending strength of modified sandwich panel with polystyreene and polyethylene were 10.17 MPa and 38.22 MPa, respectively for small samples, and 20.95 MPa for large samples.

The great advantage of using intermediate layer is apparent when a core material with high compressive strength is used. Figure 1 indicated when balsa was used as the core material without intermediate layer, the bending stress of sandwich panel reached the value of 58.83 Mpa which corresponds to the modulus of rupture of balsa wood. However, a considerable enhancement of bending strength to 113 MPa, which is 92.09% of improvement when intermediate layer was introduced in the panel. It also can be noticed in Figure 1 that the improvement of bending strength due to introducing an intermediate layer will result in a substantial increase in the weight of sandwich panel. The range of weight increases varied from 40% to 100%.

If we consider a more non-dimensional analysis using strength to overall density and/or weight ratios, which is termed material specific strength, the experimental results show that the specific strength of the two treatments were substantially similar for all large samples and higher for all small samples as illustrated in Fig 1 (B). The average specific strengths of modified and unmodified beam samples for specimens with balsa core were 238.5 and 239.5 KNm/kg, respectively. The corresponding values for samples with polyethylene cores were 11.7 and 29.8 KNm/kg, respectively. The obtained are much higher than the specific strength of concrete, which is typically in the range of 4.4-8.5 KNm/kg and approach the specific strength of other common metals such as aluminium alloy, steel alloy and titanium alloy (222, 254, and 288 KNm/kg, respectively [10]). The density of modified beam samples was notably higher than the density of unmodified beam, but it is still much lower than the properties of common material like concrete, which is around 2.3 g/cm^3. In some specific applications such as lightweight structure, specific strength is more important than other properties. The typical failure patterns of some specimens are as illustrated in the following figure.

Fig 4. Typical failure patterns of unmodified sandwich panel (above) and modified sandwich panel (bottom) with different core and intermediate layer materials

The failure patterns of the unmodified beams were mostly in the form of indentation and face wrinkling. The modifications using intermediate layers prevented such failure mechanisms, resulting in a higher bending capacity. Shear failure of the core and tensile failure at the bottom were the dominant failure mechanisms for the modified sandwich beam specimens. The results verified the earlier work of Mamalis [1] that indicated that the introduction of an intermediate layer will improve the capability of a sandwich panel to resist early indentation and/or face wrinkling.

Conclusions

The introduction of an intermediate layer significantly improved the bending strength of the new hybrid composite sandwich beams. The T-value of all four sample categories exceeded the corresponding values provided from relevant table *t*-distributions, verifying that the bending strength of the sandwich panels with intermediate layers are significantly higher than the unmodified sandwich panels.

Both the modified and unmodified composite sandwich beams exhibited excellent specific strengths at a level comparable to those of high strength metal alloys. The incorporation of natural based materials into the new hybrid composite sandwich panels has the potential to reduce costs while maintaining structural capacity with the additional benefits of improved fire resistence and insulation. These aspects will form part of the next research phase.

The result of this study shows the potential of this new hybrid sandwich panel composite to be developed further for potential use as a wall structure particularly for external cladding wall. The next stage of this research will consider the development of sustainable sandwich panel composites for stilt houses wall.

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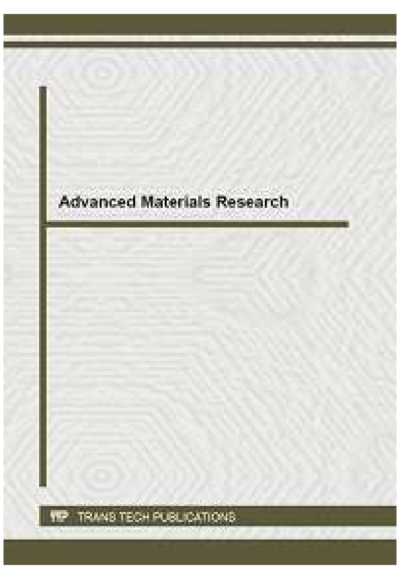

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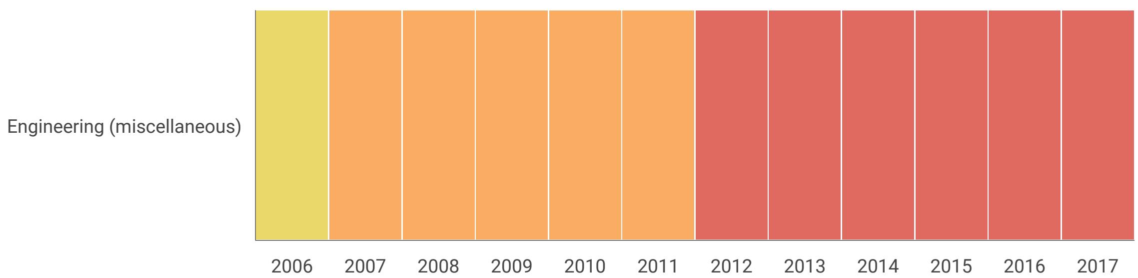

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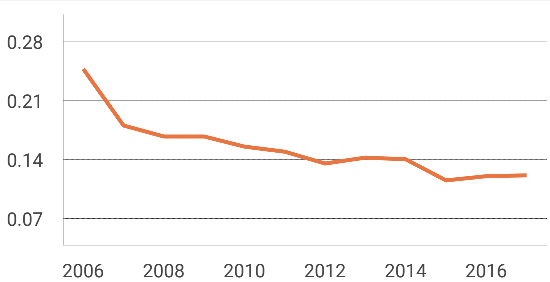

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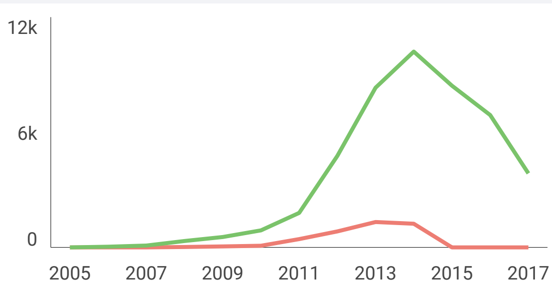

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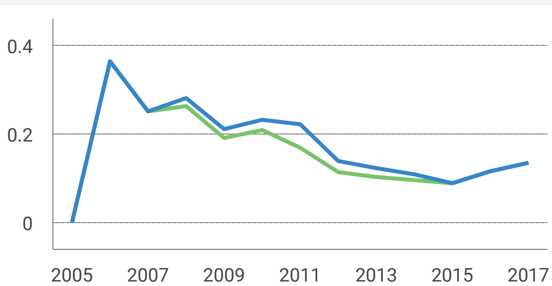

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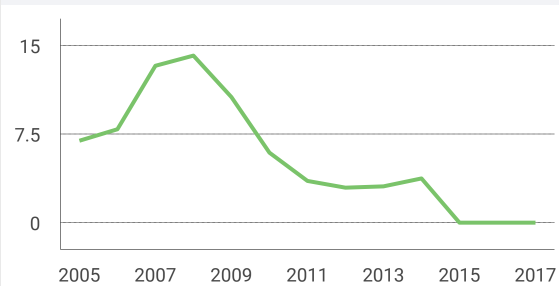

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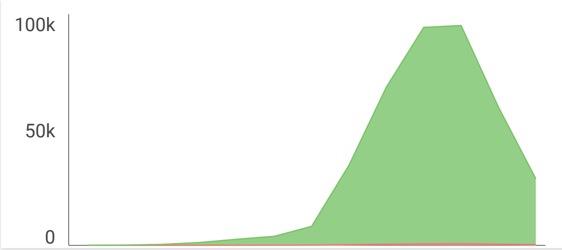

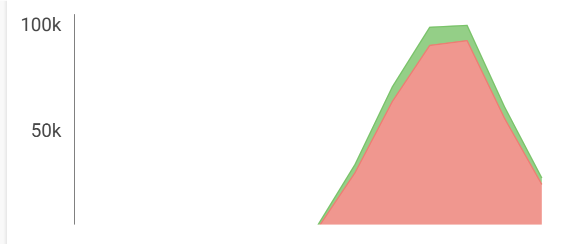

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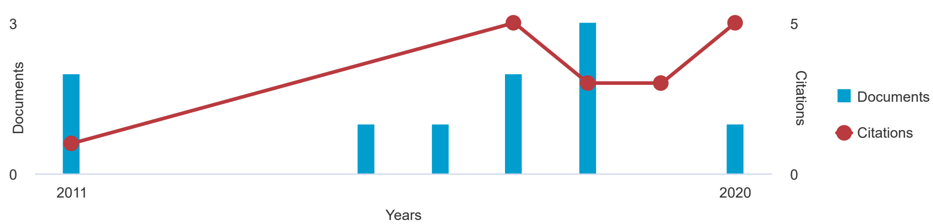

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