Test set-up for accelerated testing for characterization of long term fatigue behaviour

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SUMMARY

Fatigue testing is a time consuming test method. Fatigue life prediction methodologies based on S-N curve and residual strength require more number of tests per stress/strain level. Also cyclic heating of material like thermoplastics during fatigue restricts use of high testing frequencies. To tackle this challenge, a test set-up is proposed based on wiffle tree concept which offers fatigue testing on 4 specimens simultaneously.

Keywords: fatigue, wiffle tree, thermoplastic composites, hysteresis heating, force ratio

Introduction

Fatigue testing of materials is a time consuming. In order to characterize the long term behaviour of materials, testing times are extremely long. In polymer matrix composite materials, viscoelastic effects produce heat within the specimen under cyclic loading which limits the use of high testing frequencies. Thermoplastic are more viscoelastic than thermosets and hysteresis heating of thermoplastics further limits the testing frequencies (<5 Hz) which ultimately turns out in extremely long testing times especially in the case of high cycle fatigue(long term fatigue behaviour). Moor[1] and Al-Hmouz[2] investigated the effect of testing frequencies on fatigue behaviour of carbon fibre/PEEK laminates under cyclic tension. They observed that composites subjected to higher loading frequency showed shorter lifetimes for equal applied stresses. At higher frequencies, test specimen heat up and the matrix becomes soft and yields at lower stresses. Locally in the regions of high stress concentration, the temperature can even go above the glass transition temperature of the polymer matrix because the heat from the hysteresis loss did not have sufficient time to dissipate heat at high frequencies.

Fatigue life prediction methodologies based on S-N curves and residual strength require multiple tests per stress/strain amplitude due to large scatter in the fatigue data and ultimately result is longer fatigue testing time. This raises interest in developing a testing jig to test multiple specimens simultaneously to have fatigue results for multiple specimens in the time for fatigue testing of one specimen.

To tackle the problem of time consuming testing, Verhoef[3] made use of a test set-up which is capable of applying repeated loads to the multiple specimens simultaneously. This concept is drawn from wiffle trees used for full scale testing aircraft structures such as aircraft wings where distributed loads are applied as shown in fig.1. Such a system distributes force through a series of levers. Levers are able to rotate freely and distribute the force to the structure such that equilibrium at each pivot point is maintained as show in figure 2. Varying the arm lengths of the levers will change the force distribution to maintain equilibrium. The same principle is used in this test set-up for testing multitude test specimens. Each specimen will be loaded at a level of force depending on the designed force ratio. Force ratio is the part of the total applied force on the test set-up distributed to the individual specimen which is governed by the lengths of lever arms. For the main lever the arm lengths of lever are equal which distributes applied total force (F_{total}) equally to the two short levers. Verhoef[3] selected different lengths of lever arms for short levers which gave different force ratio on each of the specimens as shown schematically in figure 3. This was done in order to cover a large range of forces in order a get a complete picture of residual strength behaviour of glass fiber/epoxy composites. A support is attached to the test set-up to restrict the side-wise movement of the wiffle tree during test as shown in figure 2.

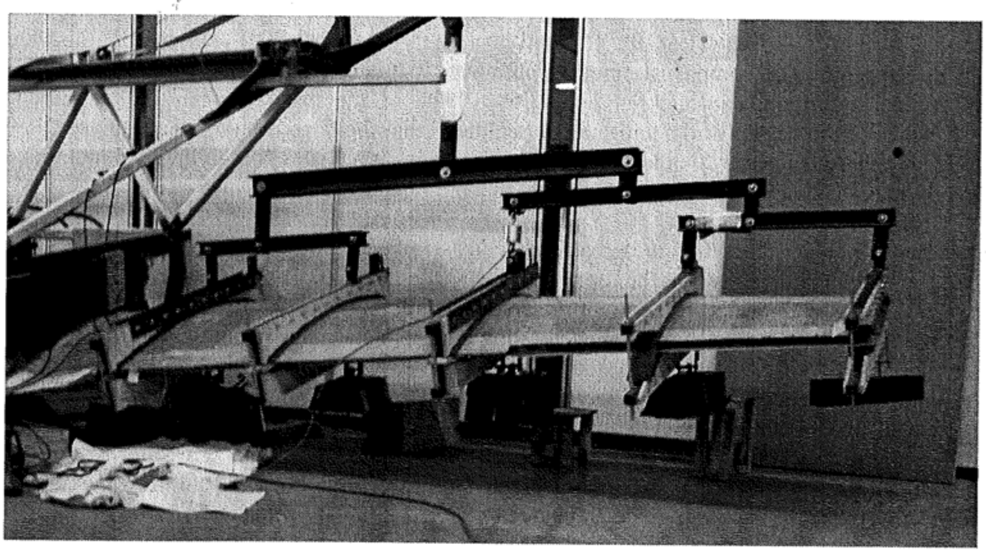

Figure 1 : Example of application of wiffle tree[3]

The main disadvantage of this design of wiffle tree test set-up with different force ratio on each specimen was that force ratio differs from the values of force ratio according to design in static situation and dynamic situation. This is due to the unbalanced effect of inertia due to different weight of levers acting on each specimen because different length of short lever result

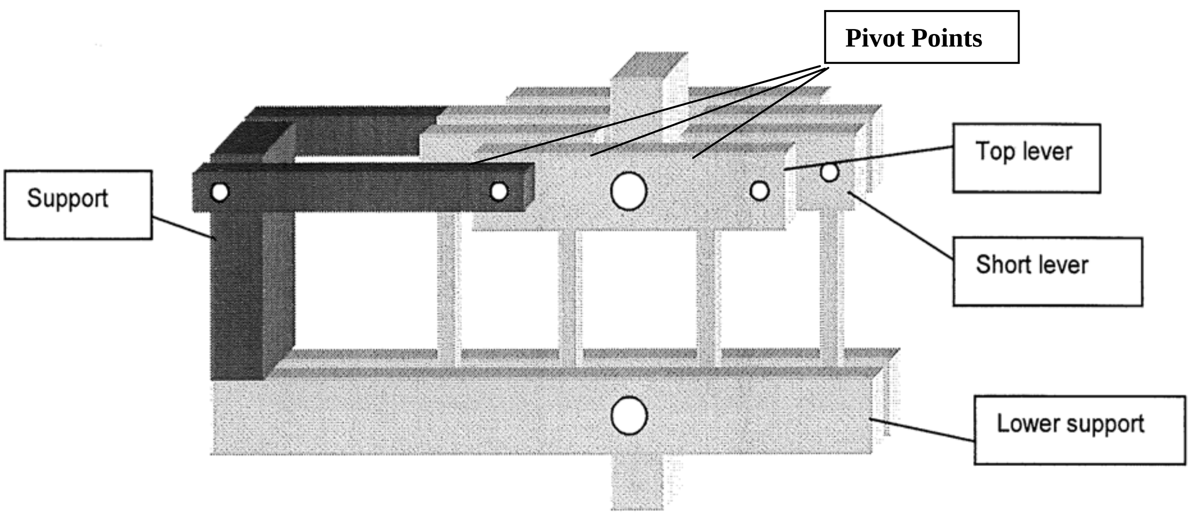

Figure 2: Schematic lay-out of wiffle tree[3]

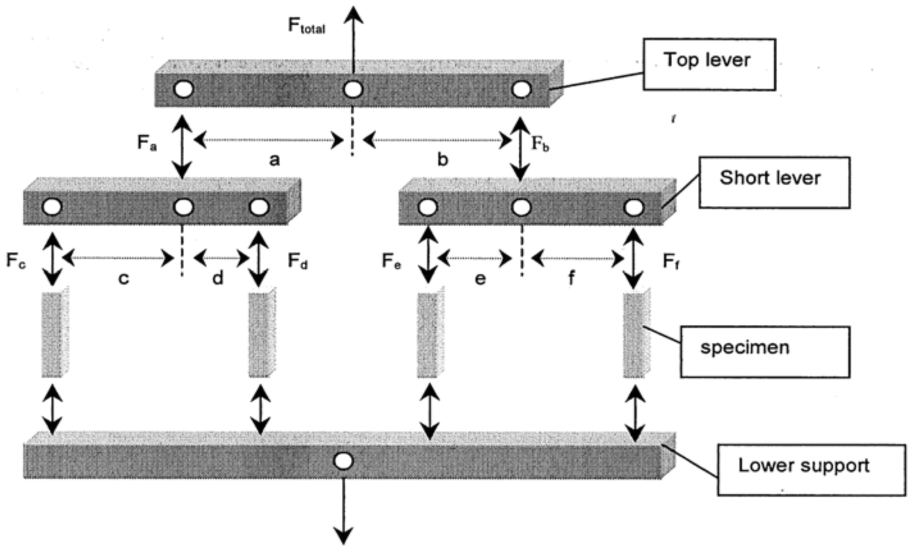

Figure 3: wiffle tree schematic with different lever arms lengths[3]

Modification to test set-up

To tackle this problem a design improvement is suggested in this work which is based on having equal lengths of levers as shown schematically in figure 4. This is expected to give an equal force ratio on each specimen during static and dynamic testing due to balanced effect of inertia on each specimen because weight of lever system distributed equally to each specimen.

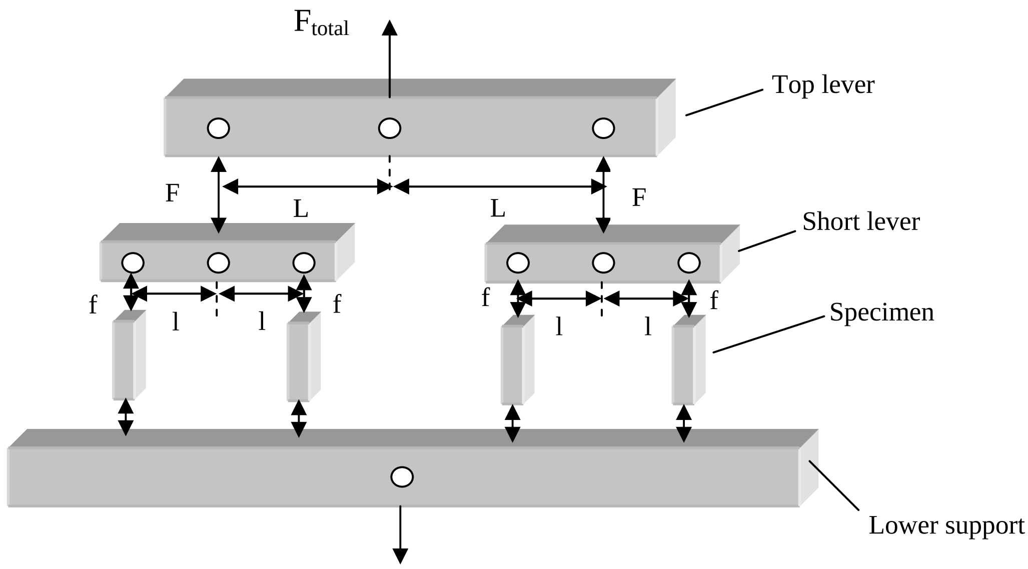

Figure 4: Modified version of wiffle tree test set-up

Evaluation of test set-up

Before using the modified version for actual testing, it is necessary to evaluate its proper functioning. The wiffle tree is designed to have equal force on each specimen, but the question is if each specimen is sharing the applied force on the test set-up equally and this load is actually applied to the specimen. It might happen that specimen could experience different force than the designed force due to friction between the bearing surfaces, play in the moving/rotating parts or that test set-up components are not exactly manufactured according to design. In this section the performance evaluation of wiffle tree test set-up is described.

Fatigue results from test set-up are only useful if the actual force on each specimen is known. For this purpose, four Aluminium dog-bone specimens were used as shown in the figure 5. Four strain gauges were bonded to each specimen in a full bridge configuration so the each specimen acts as a force transducer. First each specimen is tested individually in static test to calibrate the test specimens with the measurement system. The calibration was done repeatedly until the strain gauge measurement was equal to the force from the tensile test machine.

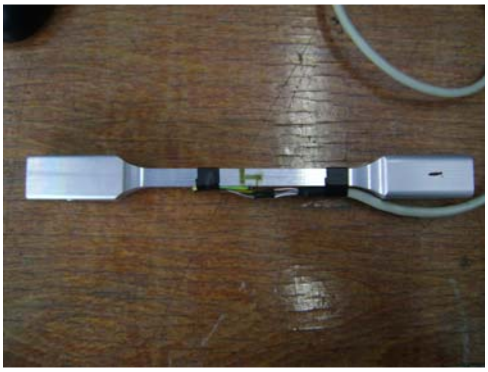

Figure 5: Specimen with strain gauges used for static and dynamic evaluation

Figure 6: Wiffle tress test set-up during testing

Static Evaluation

For the static evaluation, all four aluminum specimens were clamped in the wiffle tree with help of bolts and the wiffle tree was installed in a 250kN MTS fatigue testing machine as shown in figure 6. The wiffle tree is subjected to a single static tensile test up to a force of 20kN and curves between the applied force and the strain gauge measurement is determined as shown in figure 7.

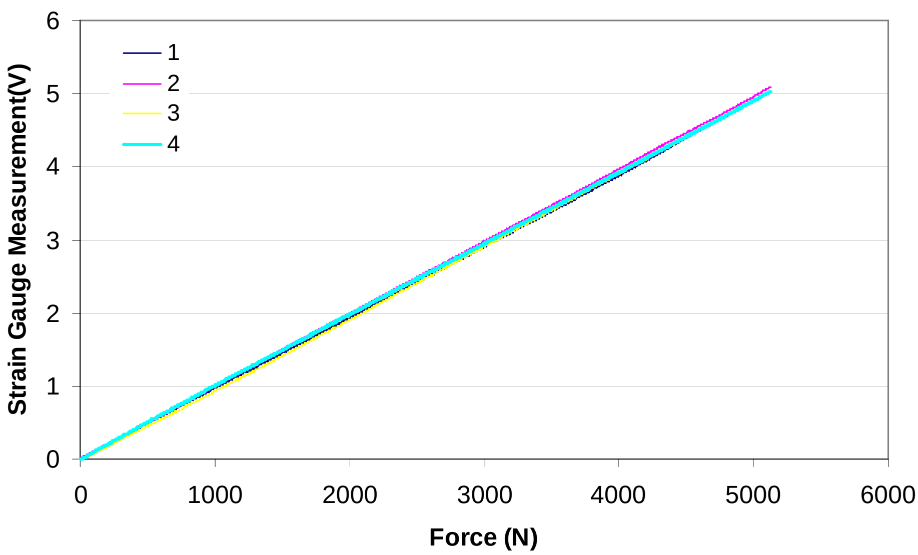

Figure 7: Strain gauge measurements on four Aluminum specimens for evaluation of wiffle tree in static situation

The curves for all four specimens show similar behavior, an indication of proper functioning of test set-up under static loading. The average force ratio measured on each specimen and compared to the ratio according to the design is listed in table 1 below.

Table 1: Comparison between measured and designed force ratios

	Modified wiffle tree			Old wiffle tree[3]		
	Force ratio	Ratio according to design	Difference(%)	Force ratio	Ratio according to design	Difference(%)
1	0.251	0.250	0.5	0.376	0.386	2.5
2	0.254	0.250	1.8	0.288	0.294	2.0
3	0.251	0.250	0.5	0.197	0,206	4.4
4	0.252	0.250	0.6	0.132	0.114	15.7

The difference in actual force ratio on the specimens and the force ratio according to the design is less than 2%. Results are also compared with the results from Verhoef[3] for which the difference in force ration ranges from 2% to 15.7%.

Dynamic Evaluation

Evaluation of the dynamic situation was performed in the same way as the static performance. Fatigue tests were performed on different frequencies ranging from 1Hz to 10 Hz with an applied force of 20kN at R=0.1. Specimens 3 and 4 were tested only at frequencies of 1Hz and 3Hz. As an example; the results of the dynamic evaluation at frequency of 3Hz are shown in figure 8.

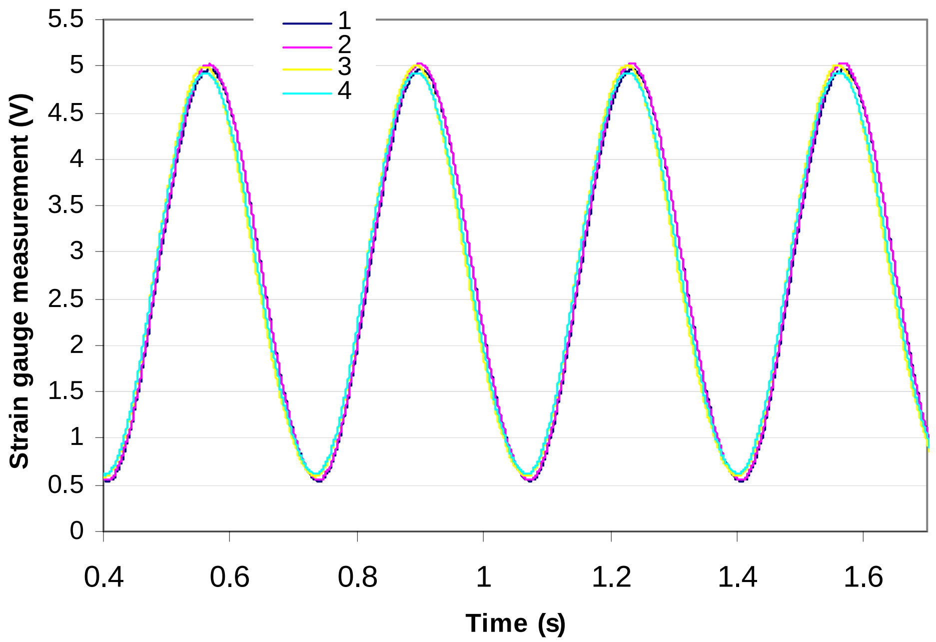

Figure 8: **Curves for dynamic evaluation test at 3Hz**

From the strain gauge measurements the maximum strain values were recorded and the force ratio on each specimen was calculated by dividing strain gauge measurement on each specimen by the total force applied on the test set-up. The R-value for each specimen was determined from peak-valley data for 10 consecutive cycles. Table 2 lists the dynamic force ratio and the R-values for each specimen and compares them to those measured in the static situation.

Table 2: Force ratios and R-values in dynamic situation

Load	R-value	Frequency	Force Ratio				Measured R-values			
N		[Hz]	1	2	3	4	1	2	3	4
20000	1(static)	-	0.251	0.254	0.250	0.252	1.000	1.000	1.000	1.000
20000	0.1	1	0.249	0.251	0.250	0.248	0.104	0.105	0.102	0.106
20000	0.1	3	0.248	0.253	0.250	0.247	0.107	0.108	0.106	0.108
20000	0.1	5	0.247	0.249	-	-	0.115	0.115	-	-
20000	0.1	10	0.246	0.250	-	-	0.138	0.139	-	-

The force ratio on all specimens in fatigue shows the same behavior as was observed in the static situation. The difference from the designed force ratio is less than 2% as was in the case of static tests. So the inertia due to the weight of the lever system does not have any significant effect on the force ratio. But the R-value increase with increasing frequency.

Table 3: Comparison of performance of modified test set-up with older version of test set-up at applied force of 20000N, R-0.1 and f=5Hz

	Modified wiffle tree			Older wiffle tree[3]		
	Force ratio	ratio according to design	Difference(%)	Force ratio	Ratio according to design	Difference(%)
1	0.247	0.250	1	0.398	0.386	3.1
2	0.249	0.250	0.4	0.302	0.294	2.7
3	-	-	-	0.205	0.206	0.5
4	-	-	-	0.127	0.114	11.4

In table 3 results of the modified test set-up in cyclic loading in tension-tension mode at a frequency of 5Hz are compared to those of the older of wiffle tree test set-up. Difference in designed and actual force ratios for the modified test set-up is less than those for the test set-up of Verhoef.

Conclusions

In this study, an effort is made to improve performance by design modification of an older wiffle tree fatigue test set-up for testing 4 specimens at the same time in order to have multiple fatigue test results for S-N curves in a shorter time. The evaluation of test set-up is performed only in static tension and cyclic tension-tension modes.

The older set-up is based on having different force values on four specimens by having different lengths of arms of short levers. In the static situation, the actual force ratio differs from the force ratio according to design from 2% to 15.7%. By making the arm length of the short levers equal, this difference is less than 2% for all 4 specimens. This is because by making lengths of lever arm equal, weight of lever system is equally distributed to the specimens. Similar results for force ratios are also obtained in the case of dynamic testing.

The modified wiffle tree test set-up is more reliable for tension-tension fatigue tests to obtain fatigue data for S-N curves in a shorter time than the older test set-up.

References

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