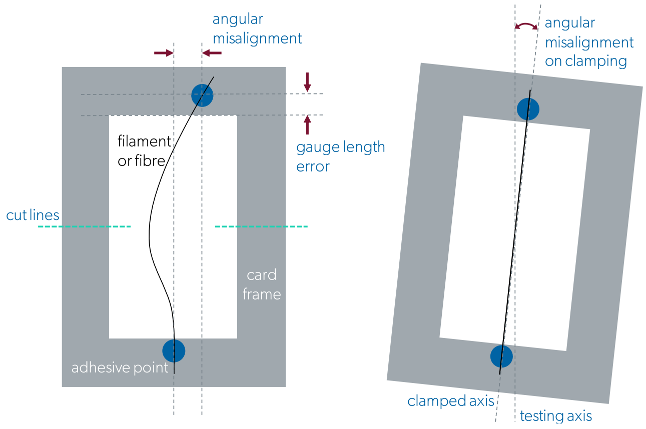
Automated dimensional and tensile testing of carbon fibres

Introduction

The strength of carbon filaments is dependent on a number of factors including the gauge length, accurate diameter measurement and the distribution of flaws within the material.

Traditionally, the measurement of the tensile properties of carbon filaments is done manually with the fibres commonly mounted onto card which generates a number of issues:

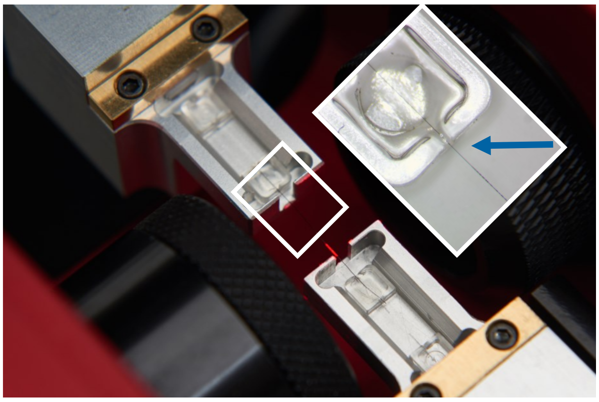
- The cross-sectional area may vary between fibres so accurate dimensional measurements are critical
- Failure of fibres can occur at different stages of the manual process by being subjected to many external and unwanted forces. Failure also occurs when the card mountings are cut prior to testing
- Misalignment of fibres and an inaccurate gauge length lead to erroneous results
- Confidence of the data is dependent on running larger data sets. Manual testing is very time consuming which may limit the number of samples being run
- The complete and automated testing solution offered by Dia-Stron addresses the issues posed by traditional and manual approach.



Advantage of the Dia-Stron system

The ASTM c1557 recommends the axis of the fibre shall be coaxial with the line of action of the testing machine to prevent spurious bending strains and/or stress concentrators [1]. Improved alignment is achieved by mounting fibres between pairs of plastic tabs with alignment features, pre-loaded in a storage cassette.

- Reduced specimen mounting time by utilising a rapid UV-curing adhesive to secure the fibres
- Reduction in the number of failed samples by eliminating most unwanted and accidental forces during preparation and running of the test
- Exact measurement of gauge length and ability to test across a range of gauge lengths allowing system compliance to be calculated. Pre-tensioning of the fibres removes any slack prior to testing. UvWin software measures the exact extension applied for tensioning and corrects the effective gauge length accordingly
- Automated, accurate, non-contact, and direct measurement of apparent fibre diameter provides precise stress and modulus calculations
- Testing throughput is increased due to a continuous and unsupervised automated process
- Automated process facilitates the generation of large sets of experimental data which allows for more detailed statistical analyses to be carried out
- Hands on operator hours reduced by 75%



Factor	Manual Testing	Automated Testing
Sample Preparation	Fibres mounted on flat paper tabs	Fibres mounted on plastic tabs with alignment grooves
Fibre Extraction	Hand held	Using vacuum/suction pen
Fibre mounting process	Manual	Using vacuum/suction pen
Fibre alignment	Depends upon user skill	Near perfect alignment with the help of grooves on plastic tabs
Gauge length	Depend on size of paper tab and location of glue (which depends on the accuracy of the paper tab length	Fixed due to locking of plastic tabs in cassettes. Different gauge length cassettes available
Specimen preparation time (set of 20 fibres)	~ 3.5 hours (excluding adhesive curing time) ~ 12 hours (including adhesive curing time)	~ 1 hour (excluding adhesive curing time) ~1.25 hours (including adhesive curing time)
Specimen mounting process	Manually lifted and placed onto test setup	Automated transfer of specimens from cassettes to test setup using ALS1500
Gauge length correction	No	Gauge length corrected after pre-tensioning the fibres
Intermediate step	Paper tabs slit manually to allow load transfer	No intermediate step
Load application	automatic	automatic
Specimen test time (set of 20 fibres	~1.5 hours (manual)	~1.5 hours (automated, can be left to run on its own
Total time	5 hours	3 hours
Total person hours (set of 20 fibres	5 hours	1.25 hours

Comparison table [2]

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Example Data – T700S

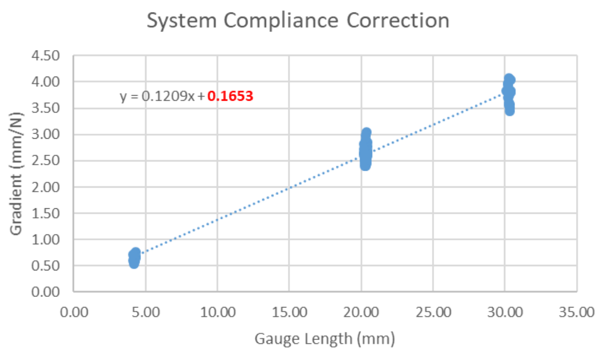
- 100 T700S fibres were selected at random and mounted and secured in 1-part plastic tabs using EMI Optocast 3553 UV curing adhesive
- Each fibre sample was exposed to 15 seconds of 365nm wavelength UV light at a distance of <5mm
- 20 specimens were mounted with a 4mm gauge length for the lower compliance set.
- 20 specimens were mounted with a 30mm gauge length for the upper compliance set.
- 60 specimens were mounted with a 20mm gauge length to form the main test population, as well as the middle compliance set

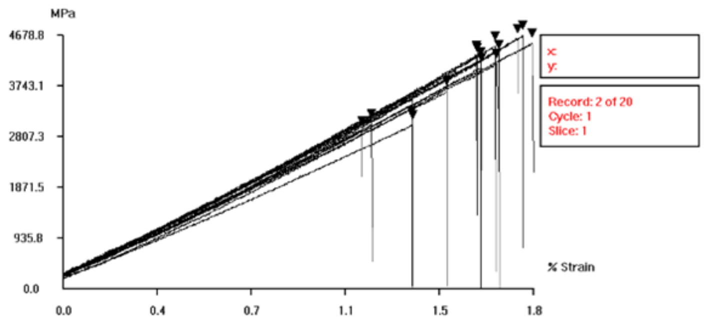
Dimensional Test

- The diameter of each specimen was measured using a Dia-Stron LDS0200
- Each specimen was tested mechanically using a Dia-Stron LEX820 with a strain rate of 1mm/min

Compliance Correction

- System compliance is obtained by using the ISO 11566 testing standard [3] whereby the modulus of one type of fibre at 3 different gauge lengths (e.g. 4, 20 and 30mm) in order to calculate the compliance factor, K





The compliance factor is inputted into the UvWin software and re-running the analysis yields the compliance corrected modulus values.

Toray T700S	Unit	Dia-Stron LDS/LEX	Product Specification
Fibre Diameter	μm	6.8	7.0
Modulus	GPa	226	230
Break Strain	%	1.6	2.1
Break Stress	MPa	4011	4900

Tensile strength comparison with manufacturer datasheet

The objective of this study was to correlate published mechanical properties of commercial grade filaments against values measured on the presented system. The data was generated by Fabio Franceschi Pereira [4].

Carbon Fiber Samples		Data sheet	DELO AD 640	DYMAX 3193
CYTEC P25	Tensile Strength (MPa)	1,380	1,660 ± 215	1,367 ± 236
	Elongation (%)	0.9	1.2 ± 0.1	1.1 ± 0.2
	Diameter (μm)	11.0	10.7 ± 0.7	10.9 ± 0.7
	Weibull Modulus	----	8.64 ± 0.14 R^2 = 0.98683	6.63 ± 0.30 R^2 = 0.90657
HEXCEL AS4	Tensile Strength (MPa)	4,280	3,901 ± 568	3,839 ± 477
	Elongation (%)	1.87	2.07 ± 0.32	1.93 ± 0.29
	Diameter (μm)	7.1	7.3 ± 0.2	7.3 ± 0.3
	Weibull Modulus	----	7.58 ± 0.15 R^2 = 0.98107	9.16 ± 0.31 R^2 = 0.94744
TORAY T300	Tensile Strength (MPa)	3,530	3,570 ± 595	3,515 ± 591
	Elongation (%)	1.5	1.7 ± 0.3	1.7 ± 0.3
	Diameter (μm)	7.0	7.0 ± 0.4	7.1 ± 0.4
	Weibull Modulus	----	6.91 ± 0.17 R^2 = 0.97183	6.71 ± 0.18 R^2 = 0.96680

Fifty carbon filaments were sampled from each carbon tow, mounted as specimens then stored on a 50-slot linear cassette. Sample cassettes were run on the Dia-Stron automated dimensional and tensile system with measurement parameters derived from the ASTM C1557 Standard.

Conclusion

The tensile properties measured on the presented system are in good agreement with published manufacturer data, including tensile strength, extension at break and filament diameter.

References: [1] Standard test method for tensile strength and Young's modulus of fibres, ASTM standards ASTM 1557 – 14; [2] F. Islam, S. Joannes, S. Bucknell, Y. Leray, A. Bunsell, L. Laiarinardrasana "Automated and advanced experimental techniques for accurate fibre strength measurement" in publication; [3] ISO 11566 – Carbon Fibre – Determination of the tensile properties of single fibre specimens; [4] F. Franceschi Pereira "Influence of sample preparation on carbon fiber single filaments mechanical characterization", Podium Presentation, Carbon 2015 Conference, Dresden (2015)