Breaking tests of fused silica fibres conducted with high speed photography and video imaging

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Poster № 26

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Introduction

The 40 kg mirrors of the Advanced LIGO (aLIGO) interferometers will be suspended on four circular cross-section silica fibres with diameter 400 μm [1] . The fibres will be pulled and welded to ears on the sides of the mirrors using a CO_2 laser beam (see figure 1). A preliminary study of the fabrication, profiling, and breaking of flame and laser pulled silica fibres has been performed. Some empirical regularities have been observed in the series of breaking experiments. To understand the reasons for fibres breaking and factors leading to strength reduction we performed a series of supplementary experiments including photographic and video recording of fibre fracture.

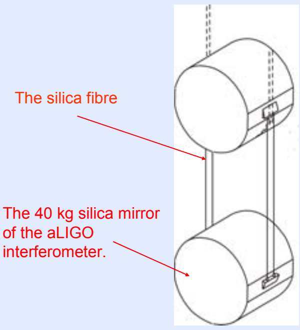


Figure 1. The lower (fully monolithic) stage of aLIGO test mass suspension.

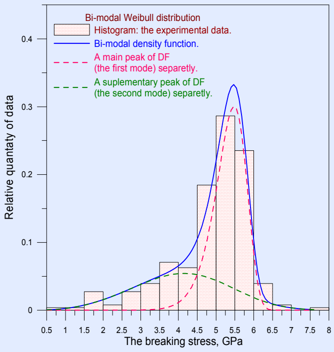


Figure 2. Occurrence of two peaks of a density function is indicative of two independent mechanisms of breaking.

Statistics of the breaking data

To amass suitable statistics, an ensemble of fibres (pulled by hand in a H_2-O_2 flame) were tested. The fibres were stretched until they broke on a tensile strength testing machine. The technical details of the experiment and stock preparation are reported elsewhere [2]. The statistics of breaking are described using a so-called "Weibull" distribution (WD). The histogram cannot be approximated by a single narrow peak; however it can be well described by a bi-modal WD density function incorporating two peaks, one of which is tall and the other (located in the region of weak fibres) is small and wide. We note that thick fibres (about d > 200 μm) contribute mainly to the small peak while the thin fibres contribute generally to the large peak. It is indicated in the literature [3] that two-peak distributions represent breaking of fibres caused by two independent fracture mechanisms. The origin of breaking cannot be drawn from statistical data and additional research methods are required.

Fibre photography

To investigate the fracture of fibres we synchronised breaking with a light flash, while a Canon 350D SLR camera was focused on the fibre to capture the break. The initial point of breaking corresponds to the point of minimum diameter (and hence maximal tensile stress) for many fibres, see figure 3. Note that breaking of pristine silica fibres [3] is different from the behaviour of other glass objects. In most cases the strength of glasses is determined by the randomly distributed surface microcracks. The largest crack functions as the weakest point. A random distribution of the origin of the break was not observed on the photographs; instead all strong fibres (contributed in the large peak on the figure 2), which were photographed, broke at the point of the maximum tensile stress.

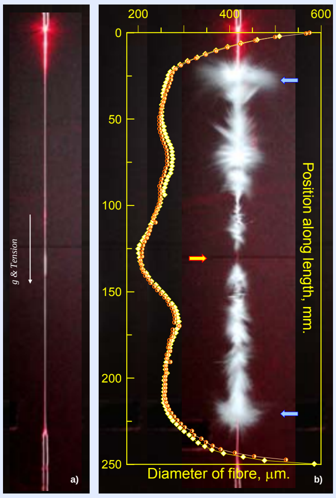
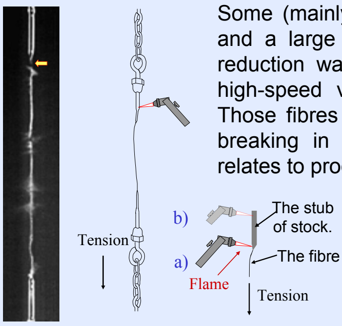


Figure 3. Two photos of a fibre before (**a**) and during (**b**) breaking. The diameter profile vs position along the length superimposed with breaking photo ***b***. The initial breaking point shown by a yellow arrow.

Breaking at the fibre neck



Some (mainly thick) fibres manifested small strength and a large spread of data. The origin of strength reduction was found during our experiments with a high-speed video-camera (Photron Fastcam SA-1). Those fibres broke in the neck region in contrast to breaking in the middle (figure 4). Such behaviour relates to procedures of the experiment preparation.

Figure 4 (left). A frame from the video record – the fibre was broken at the top end on the neck.

Figure 5. The alignment of the test assembly.

Figure 6 (on the right). Shift of heating point from **a)** to **b)** allows us to restore the strength of the thick fibres.

To align and remove excess bending the fibre assembly was stretched and locally heated until the silica was molten (see figure 5). Heating applied to many of the fibre ends was employed since it made the neck region more symmetrical. After observing the phenomena of neck fracture we displaced the heating point a few millimetres away from the fibre (see figure 6). That allows us to restore the strength of the thick fibres to a strength above 5GPa, see data shown on figures 7 and 8 by green diamonds. Note that fibres thicker than 400 μm were always broken at the stock (i.e. not in the fibre) while they were loaded over 60 kg. Those data are shown by the solid diamonds.

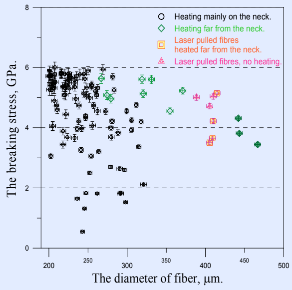


Figure 7: The breaking stress of fibres heated for alignment a few mm outside of their neck or not heated at all. Fibres pulled using the H_2-O_2 flame and CO_2 laser are presented on this graph.

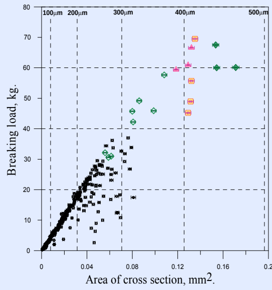


Figure 8. The data shown in fig. 7 presented as breaking load vs cross sectional area. The vertical grid shows here the fibre diameter. Laser pulled fibres heated for alignment manifest a large spread of data.

An interesting effect is observable in figure 3. The structure shown by the blue arrows were not evident if the fibre ends were not aligned through heating.

Breaking of fibres pulled by a CO_2 laser machine.

For the breaking experiments we prepared a shortened version of the aLIGO fibres; they were 90 mm in length with a thick short section at the ends.

The rectangular points in figures 7 & 8 represent the fibres which were heated for alignment as shown in figure 6b. For comparison we conducted a short series of tests without any alignment at all. These data (marked by red triangles) show a smaller spread. The fibres with breaking stress > 4.3GPa broke in the middle at the point of maximal tensile stress. The other fibers with lower breaking stress broke elsewhere along the length (see figure 9).The strength reduction can be associated with the thermally induced stress; no other mechanisms were detected. The thermal stress of stocks appear to be a more significant factor for the laser pulled fibres rather than for the flame pulled fibres of the same diameter, all experimental conditions being the same .

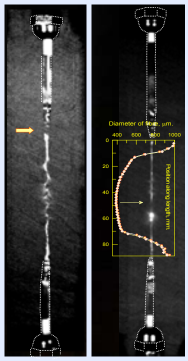


Figure 9. The breaking of two similar fibres that were pulled sequentially on the CO_2 laser machine. The low contrast details are contoured by dotted lines. **a)** – the stocks were heated by flame a few mm away of the necks; **b)** – no heating (no alignment) was employed.

Acknowledgements

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