Simple Room Temperature Method for Polymer Optical Fibre Cleaving

David Sáez-Rodríguez, Kristian Nielsen, Ole Bang, and David John Webb

***Abstract*—In this paper, we report on a new method to cleave polymer optical fibre. The most common way to cut a polymer optical fibre is chopping it with a razor blade; however, in this approach both the fibre and the blade must be preheated in order to turn the material ductile, and thus, prevent crazing. In this paper, we make use of the temperature-time equivalence in polymers to replace the use of heating by an increase of the cleaving time and use a sawing motion to reduce fibre end face damage. In this way, the polymer fibre can be cleaved at room temperature in seconds with the resulting end face being of similar quality to those produced by more complex and expensive heated systems.**

***Index Terms*—Polymer optical fibre (POF), POF for sensing and telecommunications, POF handling, polymer optical cleaver.**

I. Introduction

POLYMER optical fibre (POF) is a growing, enabling technology in the fields of sensors [1] and telecommunications [2]. It has several potential advantages with respect to the more established silica optical fibre (SOF) technology, because of features such as the lower density (leading to lower installed weight), smaller Young's modulus or price and, for the commercial thick multi-mode POFs, ease of installation.

However, POF—especially single mode POF—is not a mature technology yet and some issues must be addressed to reach a similar state of the art to SOF. Some of these aspects have been addressed; for instance the fibre losses have been significantly reduced by substituting fluorine atoms for hydrogen [3] and the photosensitivity to UV radiation (which makes feasible the fabrication of optical devices) has been improved by the addition of different kinds of dopants [4]–[6] or by taking advantage of the relationship between photodegradation and stress [7]. Other photosensitive polymers, such as TOPAS, have been used to reduce the humidity sensitivity [8], [9]. Finally, other aspects of the handling of the polymer fibre have been improved, such as cleaving and connectorization [10]–[16]. Cleaving POF is not as easy as cleaving SOF due to the complex mechanical properties of polymers [17]. In SOF the cleave is carried out into two steps [18]: first a diamond blade forms a crack on the fibre surface, which creates a stress concentration at the crack tip; second, the fibre is pulled axially to propagate the crack taking advantage of the stress in the tip. This method provides a good quality end-face in brittle materials. However, in ductile materials, such as POF, it is not possible to perform the second step of this method at room temperature since the stress in the crack tip favours the appearance of crazing [19]; only when the material is at low enough temperature is it brittle enough to perform the second step [16]. In order to address this problem, two methods have been implemented. On the one hand, different technologies to cleave POF have been investigated, including the use of a laser, a semiconductor dicing saw, or a focused ion beam [11], [12]. However, these methods are not currently frequently used because they are expensive, complex or time consuming.

On the other hand, a simpler approach involving the use of a razor blade to cut the POF has been developed [13]–[15]. In this method, the fibre is effectively chopped; it is placed on a flat plate and a razor blade is pushed through it from the top, perpendicular to the fibre axis. Both the blade and the fibre must be pre-heated at a temperature near to, but below, the glass transition temperature to make the polymer ductile. This means that different polymers require different cleaving temperatures [15]. As the material is more ductile at the higher temperature, the stress in the crack tip is decreased and therefore crazing does not appear. Despite this being the most used method nowadays, it is still difficult to implement outside of the laboratory because it requires an electronic temperature control of both the blade and the fibre as well as a precise control of the blade speed, requiring a power supply. This contributes to the size, weight, complexity and cost of the cleaver. Finally, the heating of the fibre and blade contributes to a time consuming termination process.

The time-temperature equivalence principle is well known in the field of polymers. In its simplest form it implies that the viscoelastic behaviour at one temperature can be related to that at another temperature [17]. As a consequence, a material transition state (for example from brittle to ductile) produced at one temperature can happen at a lower temperature if the polymer is stressed for enough time. This suggests that it should be feasible to substitute time for temperature in the method reported in [13]–[15], so that by cleaving the POF slowly enough, the stress at the crack tip can relax and enable ductile behaviour (see [17] where the stress relaxation of PMMA is illustrated in Fig. 7.3.). Cleaving POFs of different polymers would then not require different temperatures, but different times. In this paper, we report, for the first time to our knowledge, a new method to cleave POF

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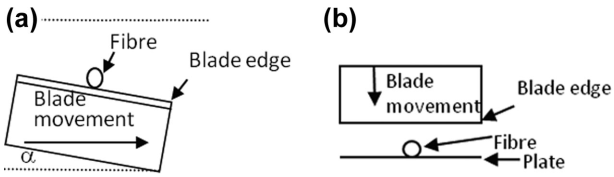

Fig. 1. (a) Sawing cleave, (b) Chopping cleave.

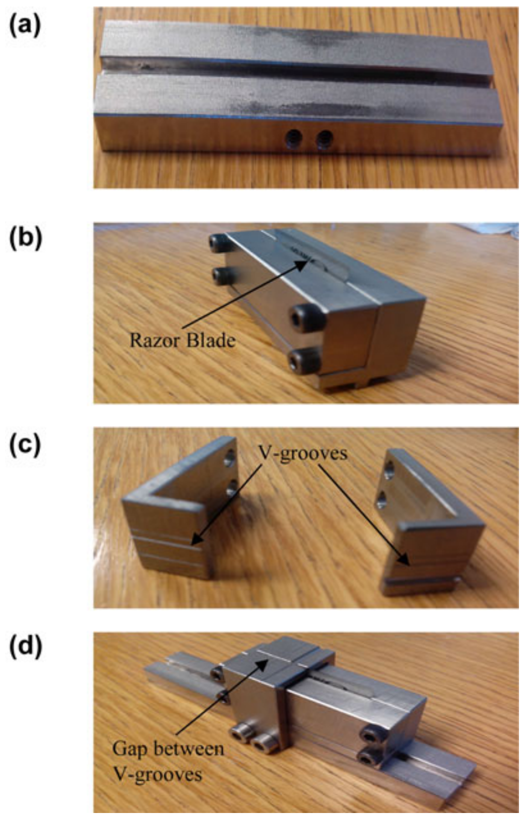

Fig. 2. (a) Rail, (b) blade holder, (c) fibre grooves, (d) assembled cleaver. Note that the rightmost pair of grooves facing each other in (d) are of different sizes due to a machining error and were not used.

based on the temperature-time equivalence in polymers. In this new method the blade is moved through the fibre one time with a small angle between the direction of motion and the edge of the blade. We therefore refer to the process as sawing to distinguish it from the chopping motion used in previous works [13]–[15]. Fig. 1 shows both kinds of cleaving—note how the sawing is performed from below, this is not essential but is rather a feature of our cleaver design.

II. Cleaver Description

The cleave was studied for different speeds and angles of the blade and it was found that the crazing in the end-face disappears for lower speeds and small angles due to the relaxation of the crack tip stress. This new method does not require heating of the POF or the blade to obtain a good end-face. Fig. 2 shows the designed polymer cleaver, consisting of four pieces, all fabricated in stainless steel. The first and second pieces in

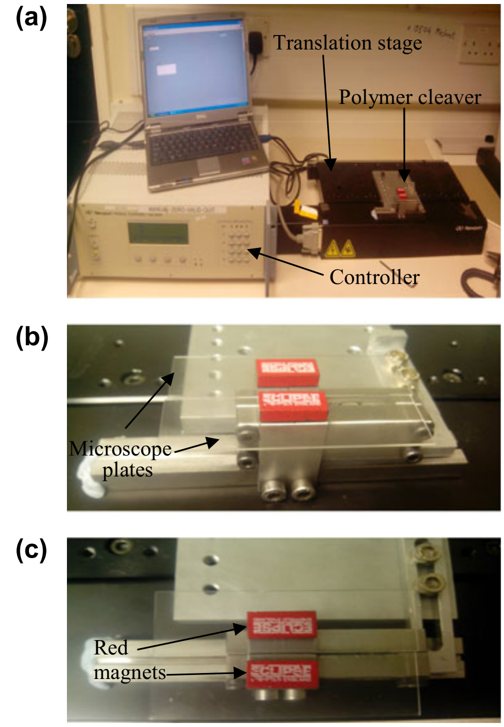

Fig. 3. Setup to control the blade velocity. (a) Full setup, (b) close-up view (c) alternative close-up view.

Fig. 2(a) and (b) form a rail and a blade holder, the pieces being designed to slide and hold the blade. The blade can be set with an angle from 0° to 90° with respect to the holder. The third and fourth pieces in Fig. 2(c) are screwed to the right and left side of the first piece; both of them have v-grooves machined in the top surface to hold the POF. Once the cleaver is assembled, a small gap remains between the third and fourth pieces, which is perpendicular to the v-grooves. Through this slot the blade moves to saw the fibre. Fig. 2(d) shows the mounted cleaver.

Fig. 3(a) shows the set-up to control the blade speed during the experiments investigating the sawing process, incorporating a translation stage and its controller (driven by LabVIEW software). In Fig. 3(b) and (c) is a magnified image of the cleaver placed on a non-moving part of the translation stage, whilst the moving stage pushes the blade holder via a clamp. The POF is placed in the v-groove and held in place by two rectangular microscope plates and the two red magnets shown in Fig. 3(b) and (c). The plates are separated by a gap just large enough to pass the blade. In order to characterize the cleaver, a PMMA microstructured polymer optical fibre (mPOF) was fabricated at the Technical University of Denmark; we used mPOF because it is more difficult to cleave it than a step index fibre because of the holes. The fabrication details are given in [7]. Table I shows a set of sawn surfaces of the fibre for different sawing times and blade angles.

During the experiment, first, the blade angle was set and the mPOF was sawn for different sawing times from 60 to 0.25 s, where the sawing time is defined as the time necessary to saw through the full fibre. Second, in order to check whether the blade was damaged or not, an extra cleave lasting 60 s was

TABLE I
TRANSVERSAL SECTION OF THE MPOF CUT USING THE POLYMER CLEAVER FOR DIFFERENT SAWING TIMES AND BLADE ANGLES

Sawing time (s)	1 degree	5 degree	10 degree	20 degree	30 degree	40 degree	60 degree
60							
40							
20							
10							
5							
2.5							
1.5							
1							
0.5							
0.25							
Check point 60 s							

made at the end of the series to compare with the first 60 s cleave.

III. Key Points in a Proper Cleave

There are four key points, which must be considered to obtain a proper cleave: sawing time, polymer stiffness, polymer toughness, and the sawing contribution. First, the fibre must be sawn slowly enough to avoid the appearance of crazing; lower velocities allow the relaxation of stress at the crack tip due to the temperature-time equivalence, as explained in the introduction. The sawing time is determined by both the speed and the angle of the blade. For a given speed, the smaller the angle the longer is the sawing time of the whole fibre, in contrast, for an angle of 90° the sawing time is minimum. Table I shows that there is a slight dependence of the time at which crazing appears on the angle, which decreases from 5 to 1 s as the angle increases.

Second, due to the low stiffness of PMMA, the polymer will be bent during the sawing process as a consequence of the blade force necessary to initiate the cleave. This bending produces compression on the cleave side and tensile stress in the opposite side of the fibre. As the blade progresses through the fibre, the stress increases because the sectional area of the fibre under stress is reduced. Once the stress overcomes the material's tensile stress, the polymer fibre will break causing an uncontrolled cleavage in the stressed region. This effect can be reduced by increasing the stiffness, achieved by reducing the gap in the sawing area or increasing the fibre diameter. As explained, the microscope plates are used to reduce this gap to the blade thickness, which was 90 μm. It was experimentally checked that the broken part of the fibre corresponds to the end of the cleaving process and therefore is a consequence of the final uncontrolled cleave.

Third, the blade force to initiate the cleave will depend on the toughness of the polymer and the sharpness of the blade. This force should be as small as possible to avoid bending the fibre during the cleave and for this reason, the blade must be as sharp as possible.

Finally, the force necessary to initiate the cleave also depends on the blade angle; for large angles the cleave approaches the chopping motion used in [13]–[15]. In the process of chopping, the only contribution to initiate the cleave is the pressure of the blade on the fibre surface, however in a sawing process the friction of the blade on the fibre surface also contributes to initiate the cleave. In Fig. 4 we show the fibre end-face for a sawing time of 40 s with two different angles, (a) 1° and (b) 60°. In both pictures we see the typical roughened area followed by the missing piece of fibre previously explained. However, in Fig. 4(b) there is an extra feature just where the cleave starts, which is visible because the image is defocused. This is because this part of the cleave is not in the same focal plane as the rest. We think that this occurs because of an excess of force used to initiate the cleave at higher angles, which makes an uncontrolled start to the cleaving.

Therefore, according to these results a commercial cleaver with all components operating at room temperature should be designed to saw the POF and work with angles from 1° to 5° reaching a tradeoff between the velocity and the angle of the blade. While smaller angles allow the use of higher blade velocities, crazing appears at longer sawing times for such angles.

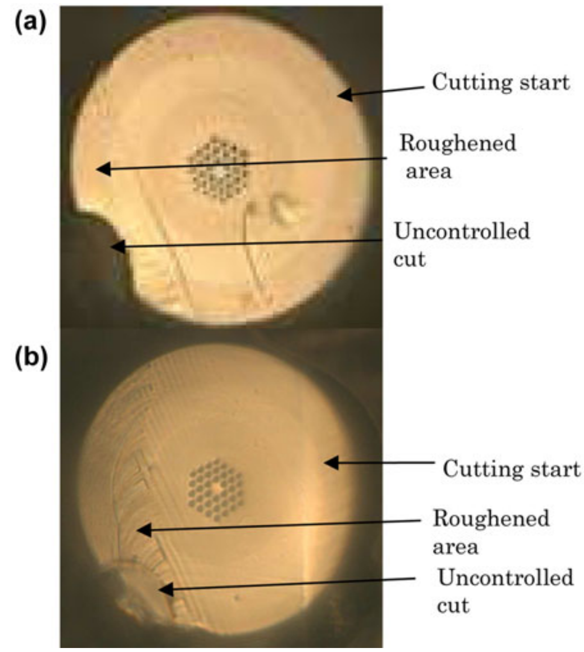

Fig. 4. Cleave end-surface for a sawing time of 40 s for two different blade angles. (a) 1° (b) 60°.

It is important to note that this range of angles allows us to work with velocities near 1 mm/s; sufficient high to make use of a mechanical damper system, rather than requiring a precision motion system, improving considerably on both the cost and the portability of the previously described cleavers [13]–[16]. In addition, the gap in the sawing area must be as small as possible to minimise fibre bend and the blade must be as sharp as possible.

IV. Conclusion

In conclusion, a new technique for cleaving single mode POF has been investigated. The process involves sawing rather than chopping the mPOF in order to reduce the initial damage to the end-face. Moreover, it takes advantage of the temperature-time equivalence principle of polymers in order to allow the fibre to be cleaved with all components at room temperature. The maximum sawing time for a PMMA mPOF has been investigated for different blade angles, with the conclusion that the blade angle should be between 1° and 5° with sawing times longer than 5 s. Cleaving an identical TOPAS mPOF with a much lower glass transition temperature [15] would, according to the time-temperature equivalence principle, require shorter time.

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