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Self-heating effect on ultra-high molecular weight polyethylene fibres and composites

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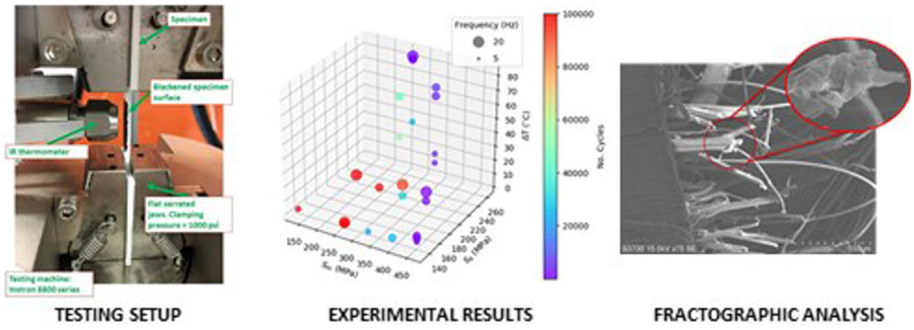
HIGHLIGHTS

- Ultra-high molecular weight polyethylene (UHMWPE) fibres and laminates subjected to monotonic tensile loads experienced an increase in temperature.
- Fatigue tests performed on the laminates revealed a strong dependency of the fatigue life on the testing conditions.
- Polymer matrix composites reinforced with UHMWPE fibres can generate a significant amount of heat when subjected to cyclic loadings.
- The maximum temperature measured in UHMWPE reinforced specimens before failure was 102 ± 1 °C.
- Depending on the fatigue parameters, the specimens showed two different types of failure modes: mechanical or thermal.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper investigates the self-heating effect observed during testing ultra-high molecular weight polyethylene (UHMWPE) fibres and their composites, in particular Dyneema® SK76 fibres and Dyneema® HB26 laminates. Monotonic and cyclic tests were carried out at strain rates between 0.00833 s^{-1} and 250 s^{-1}, frequencies up to 20 Hz, and different mean stress, amplitude stress and stress ratios to evaluate the self-heating effect developing in the materials. Measurements of the specimen's temperature were carried out using a thermochromic liquid crystal paint and an infrared sensor. Experimental results showed that the temperature increased during fibre testing by as much as 13.2 ± 0.2 °C and, even though the maximum temperature was below the melting temperature of the material, melting was observed. Tension-tension cyclic tests showed that the fatigue life of the coupon specimens significantly depended on the testing conditions. In some cases, the measured temperature was as high as 102 ± 1 °C. Depending on the fatigue parameters, the laminates showed two different types of failure modes: mechanical or thermal. Hence, it is important to take into account self-heating effects when designing engineering parts reinforced with UHMWPE fibres.

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1. Introduction

Polymeric composite materials which are subjected to external loadings generate heat as a form of energy dissipation. Generally, the constituent materials of polymer composites, i.e. fibres and resin, have low thermal conductivity compared to metals and hence are not able to quickly dissipate the generated heat through radiation, convection and conduction, which can cause degradation and eventually lead to failure. When a composite is cyclically loaded, there is a competition between the heat generated and the heat dissipated in the system. Ratner and Korobov [1] showed that three different self-heating scenarios are possible. If the temperature of the specimen remains close to the ambient temperature, the material is in a so-called "low-temperature" stable regime. Where the heat removal occurs only at higher temperature, the material is in a "high-temperature" stable regime. If the temperature rises without temperature stabilisation, the material is in an "unstable" regime. Many published articles confirmed these observations through experiments for composites reinforced with carbon fibre [2–4] and glass fibre [5–7] for example.

High performance fibres made of ultra-high molecular weight polyethylene (UHMWPE) have been increasingly used in multiple applications, such as ballistic protection, slings and ropes, and medical devices since their first synthesis and commercialization in the 1980s. However, one of the major drawbacks of this material is its relatively low melting point, which limit its use to cryogenic and ambient temperatures [8]. In fact, an increase in operating temperature facilitates the viscous flow with a consequent reduction of the mechanical properties. Various authors showed that the strength and the elastic modulus of UHMWPE fibres decreased with increasing temperature [9–13]. Egan and Delatycki [14] performed static fatigue tests on different types of high-density polyethylene (HDPE) fibres synthetised from polyethylene with different molecular weight M_w. They showed that the fatigue life of these fibres mainly depended on the molecular weight M_w of the constituent polymeric chains. The higher the M_w, the longer the fatigue life of the fibres. In fact, fibres with longer polymeric chains would have fewer chain-ends per unit length and hence less prone to chain slips with consequent lower creep rates. Humeau et al. [15] performed fatigue tests on braided ropes made of Dyneema® fibres. They showed that the heating developing in the ropes depended on the applied stress, frequency, and environment temperature. The maximum temperature reached by the ropes was 28 ± 1 °C when a maximum applied stress of ~ 1100 MPa and a frequency f = 1 Hz were used. The authors also pointed out that friction and abrasion could significantly lower the lifetime of the material. Kazanci et al. [16] noted that the fatigue response of composites reinforced with UHMWPE fibres depended on the type of matrix used to bind the fibres. Highly branched resins were beneficial to lengthen the fatigue life of the composites. Self-heating effects were not investigated as these are negligible in short-term fatigue experiments. Niinomi and coworkers [17] fabricated specimens by pressing UHMWPE powder with different molecular weights M_w. Contrary to what was reported in [14], the authors did not observe an increase in the lifetime of the specimens manufactured with higher M_w powders. Cyclic tests performed on notched specimens (frequencies up to f = 5 Hz) revealed a small increase in the specimen temperature around the crack tip area (up to 4 K).

Very few articles are available in the open literature, compared to other materials, on the self-heating effects occurring in UHMWPE fibres and its composites. The aim of this study is to investigate an eventual change in the temperature of UHMWPE fibres and composites when subjected to mechanical stresses. The effects of different specimen thickness, frequencies and fatigue parameters are investigated and supported with fractographic evidences.

2. Materials and methods

2.1. Materials

The materials investigated in this study were Dyneema® SK76 and Dyneema® HB26 prepregs, both supplied by DSM. HB26 prepregs are fabricated with SK76 fibres as the reinforcing phase. Table 1 lists the physical properties of the materials. One HB26 prepreg consists of four unidirectional layers stacked at a $[0/90]_2$ sequence. To manufacture laminates, prepregs were consolidated via the hot-pressing technique following the DSM recommended temperature vs. time cycle with a consolidation pressure of 160 bar. Two laminate thicknesses were investigated: one prepreg thick (0.33 mm) and five prepreg thick (1.44 mm). Testing specimens (Fig. 1) were waterjet cut from the manufactured laminates.

2.2. Testing methods

2.2.1. Mechanical tests

Tensile tests on the yarn were performed at room temperature using an Instron 5969 universal testing machine equipped with a 50 kN load cell. Specimens were clamped using Instron 2714–005 pneumatic capstan grips. Tests were performed on specimens with 100 mm gauge length and at three different strain rates of 0.1 s^{-1}, 0.01 s^{-1} and 0.001 s^{-1}, respectively. Fig. 2a shows the yarn testing setup.

In order to perform monotonic tensile tests and fatigue tests on coupons specimens, an Instron 8800 servo-hydraulic testing machine was employed (Fig. 2b). The force was measured with a dynamic load cell with a capacity of 25 kN. The stress was calculated by dividing the read force by the original cross section of the specimen at its gauge section. The strain was measured by tracking with a high-speed camera the relative position of two dots marked on one face of the specimen along its gauge length. Monotonic tensile tests were performed with a constant crosshead displacement between 0.0016 m/s and 5 m/s, corresponding to strain rates between 0.00833 s^{-1} and 250 s^{-1}. Tension-tension fatigue tests were conducted in load control mode with a sine waveform at a frequency between 5 Hz and 20 Hz (Fig. 2c). Specimens were loaded to S_m at a constant displacement rate of 2 mm/min before the cyclic loading. Different S_m and R (which is the ratio between S_{min} and S_{max}) levels were investigated. Fatigue run-out was set to 10^5 cycles. All tests were performed at room temperature.

2.2.2. Measurement of the specimen temperature

To measure the temperature of the specimens during the tests, two methods were adopted. In the first method, an unsealed thermochromic liquid crystal (TLC) paint was employed. An unsealed TLC is a solution of chiral-nematic liquid crystals which have a helical shape. Depending on their pitch length, the crystals reflect the light at a specific wavelength in the visible range. When the paint is applied onto a substrate, the crystals will reshape to reflect the light depending on the temperature of the substrate. Liquid

Table 1
Physical properties of the investigated materials.

Material	Density (kg/m^3)	Linear density (dtex)	
Dyneema® SK76	980	1760	
Material	**Density (kg/m^3)**	**Areal density (kg/m^2)**	**Resin**
Dyneema® HB26	980	265	Polyurethane

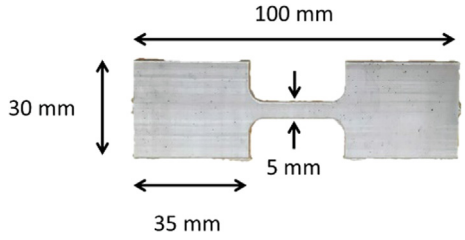

Fig. 1. Representative coupon specimen used for monotonic and fatigue tests.

crystals are also highly responsive to temperature changes (few millisecond [18]). The paint selected for the scope of the tests was the UNR20C20W from LCRHallcrest which has a red start at 20 °C and a blue start at 40 °C and a clearing point of 42.5–43.0 °C. Prior to the test, the specimens were blackened using a felt point black marker. Then, a thin layer of TLC was painted over the blackened surface. Images of the specimens were taken during the test with a Canon D6 camera. To quantify the temperature of the specimen, a HUE colour code was assigned to each pixel of the collected pictures using a Python script. The calibration of the paint was carried out prior to the testing campaign using the following procedure. A thin layer of TLC paint was spread over a piece of aluminium onto which a thermocouple was connected. The temperature of the aluminium piece was increased at a rate of 1 °C/min so that a correlation of the colour and temperature was found (Fig. 3).

The second method employed an Optris CTfast LT15F, that is an infrared (IR) thermometer with an accuracy of ± 1.5 °C and response time of 0.5 ms. The distance between the sensing head and the surface of the specimen was set to 8 mm. At this distance to the specimen, the sensor was measuring the temperature of a 2 mm diameter spot over its surface. The specimen's surface facing the IR sensor was blackened with a black marker. The emissivity, i.e. the ability of a body to emit infrared energy, was set to 0.97 (a "blackbody" is an ideal radiation source with emissivity equal to 1). The TLC paint and the IR sensor were used to measure the temperature of the yarn during tensile tests. It was not possible to use the TLC paint during fatigue tests as often the temperature of the specimens exceeded the operative range of the TLC paint.

3. Results

3.1. Monotonic tensile tests on yarns

Fig. 4 presents a series of snapshots taken during testing Dyneema®SK76 yarns at a strain rate $\dot{\varepsilon} = 0.01\ s^{-1}$ (600 mm/min).

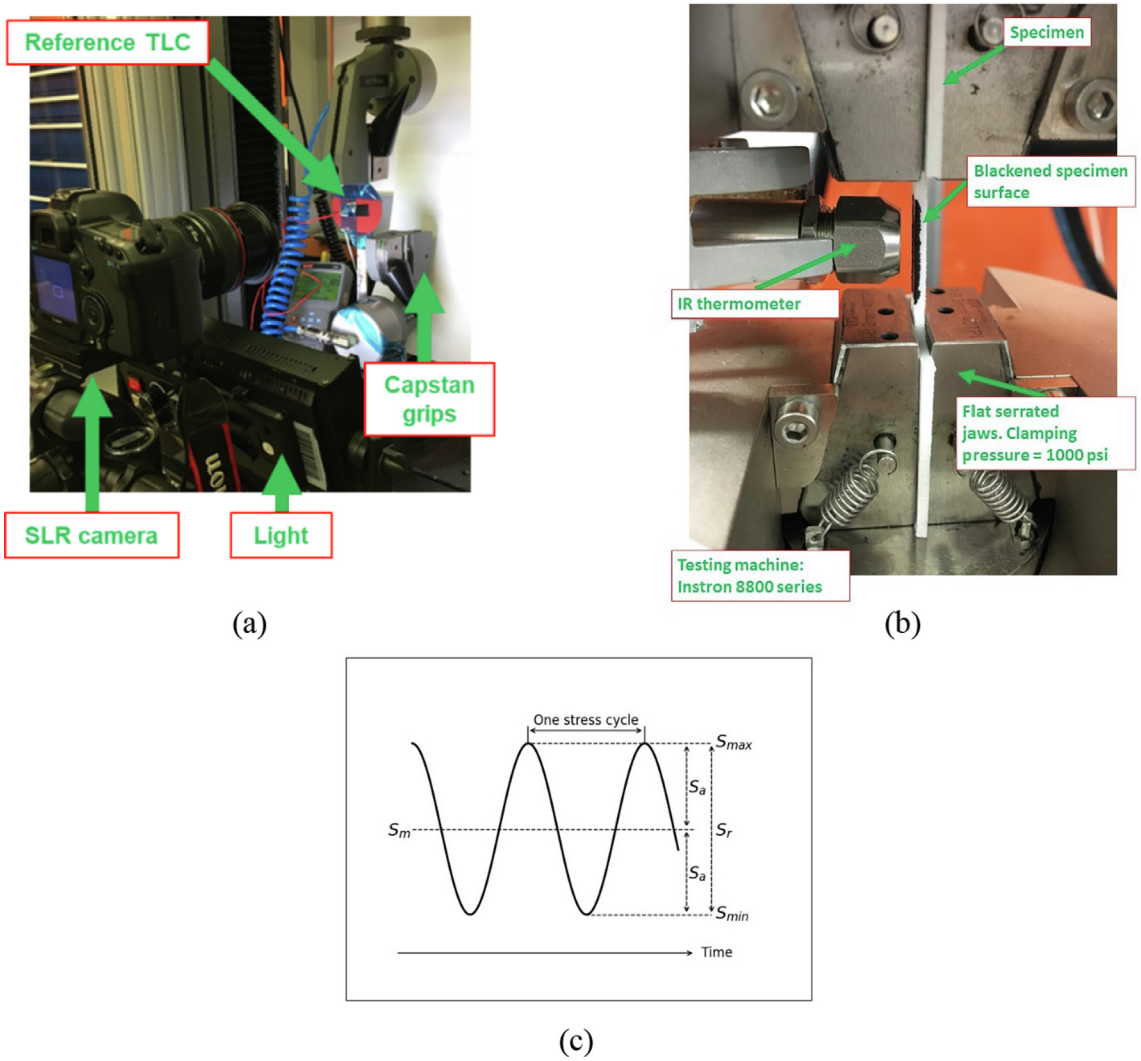

Fig. 2. (a): Yarn tensile test setup; (b): Coupon specimen test setup; (c): Fatigue cycle nomenclature.

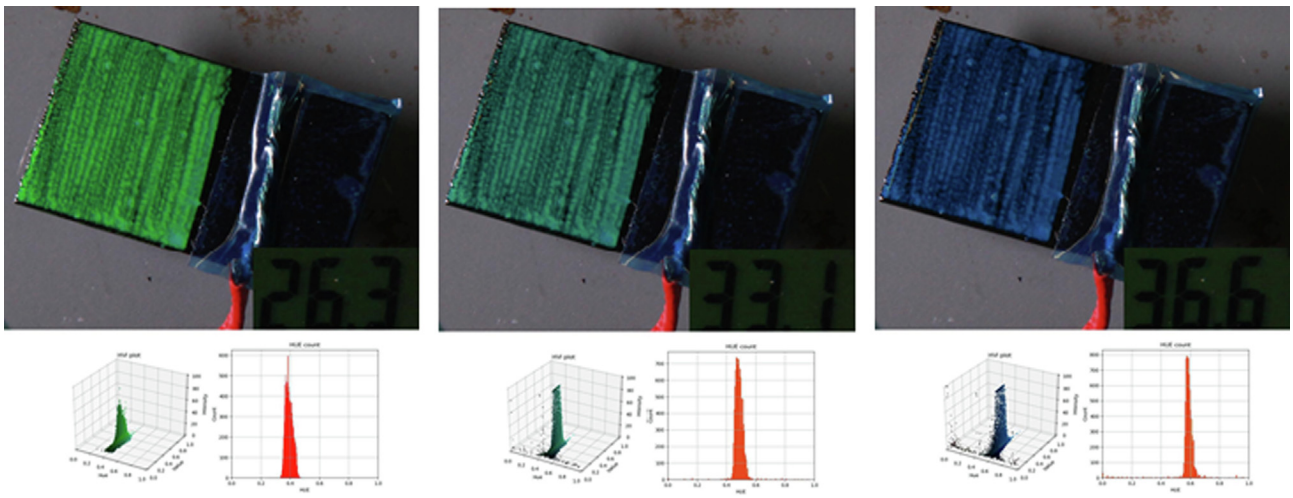

Fig. 3. TLC calibration.

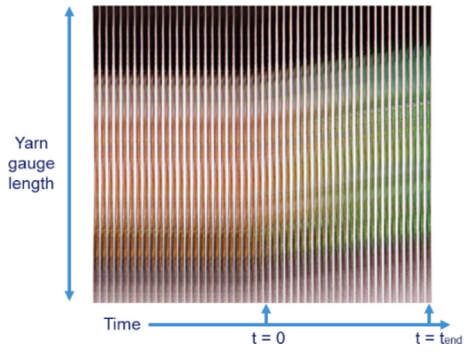

Fig. 4. Series of snapshots taken during testing a Dyneema®SK76 yarn.

It can be seen before the start of the test that the colour of the yarn was homogeneous and constant along the painted region. Once the yarn was pulled, the colour of the TLC started to change from the fibre ends inward. It shifted from orange to green and then cyan just before failure. Fig. 5a and Fig. 5b present the stress vs. time curves for tests performed with a crosshead displacement rate of 50 mm/min and 600 mm/min, respectively, overlapped with temperature measurements from the IR sensor. For the same tests, a count of the pixel and its average HUE value are presented in Fig. 5c and Fig. 5d. The drops in the stress observed before final failure, especially when the yarn was tested at lower strain rates, can be associated to the slippage of the filaments at the gripping region.

Fig. 6 shows the strength and temperature of the tested specimens as function of the strain rate. It is possible to observe that the failure strength of the yarn was consistent with historical data for the same fibre (for example in [19,20]). The maximum ΔT detected by the IR sensor was 2.4 ± 0.3 °C and 2.9 ± 0.3 °C for the tests performed at 50 mm/min and 600 mm/min, respectively. On the other hand, the maximum ΔT measured with the TLC paint was as high as 13.2 ± 0.2 °C for the tests performed at the highest strain rate. Generally, the maximum specimen's temperature was higher when tested at the higher strain rates.

It also appears that the methods employed to measure the temperature of the fibres produced different results. The reason for the discrepancy can be attributed to the measuring methods themselves. The IR sensor can accurately detect a spot temperature which is confined to the point of interest. In case of the yarn's temperature measurement, it was not possible to ensure that the IR detector was completely pointing to the yarn. The measurement might be affected by the background temperature. On the other hand, the TLC paint allowed the temperature to be measured along the whole gauge length of the yarn, i.e. a field measurement rather than a spot measurement, which would be more reliable with this setup due to a more accurate detection of the colour change.

Fig. 7 shows an image taken with a SEM of a Dyneema® SK76 filament extracted from a tested yarn. It is possible to clearly observe the individual microfibrils filament building the filament. It also appears that some of the microfibrils were further drawn due to the tensile load whilst the ends softened. Similar results were shown in [11] where a SEM image of a filament tested at room temperature revealed the fibrillar nature of the filament and mushroomed fibril ends, which indicate localised softening and melting.

Pennings et al. [11] demonstrated that the fracture process also involved breakage of lateral bonds amongst the molecules, and that the strength of the fibres mainly depend on those lateral bonds. Van der Werff and Pennings [21] referred to the stress-induced melting as the mechanism by which polyethylene chains slip out from a crystalline block and lead to the failure of the fibres. It has been shown in [22] that the irreversible (plastic) work that the fibres experience during a mechanical tensile stress is converted to heat. According to Smith and Wang [23,24], when polyethylene fibres are subjected to tensile loadings, the crystals along the axial direction of the fibres slip past each other and, to do so, localised melting occurs at microscopic scale level which would, however, almost instantaneously recrystallise. This is the reason why the broken ends of the fibres appear molten, even if the tests are conducted at room temperature.

Even though the ends of the fibres appeared softened, the maximum temperature detected during the tests were significantly lower than the melting temperature of the un-stressed fibres. Experimental values were also affected by heat dissipation phenomena and hence it would not be possible to measure temperatures as high as the melting temperature of UHMWPE. In order to capture local, microscopic heat generation, and hence establish this phenomenon in more depth, advanced experimental techniques (for example, a photomultiplier) must be used to quantify the heat generated during mechanical stresses.

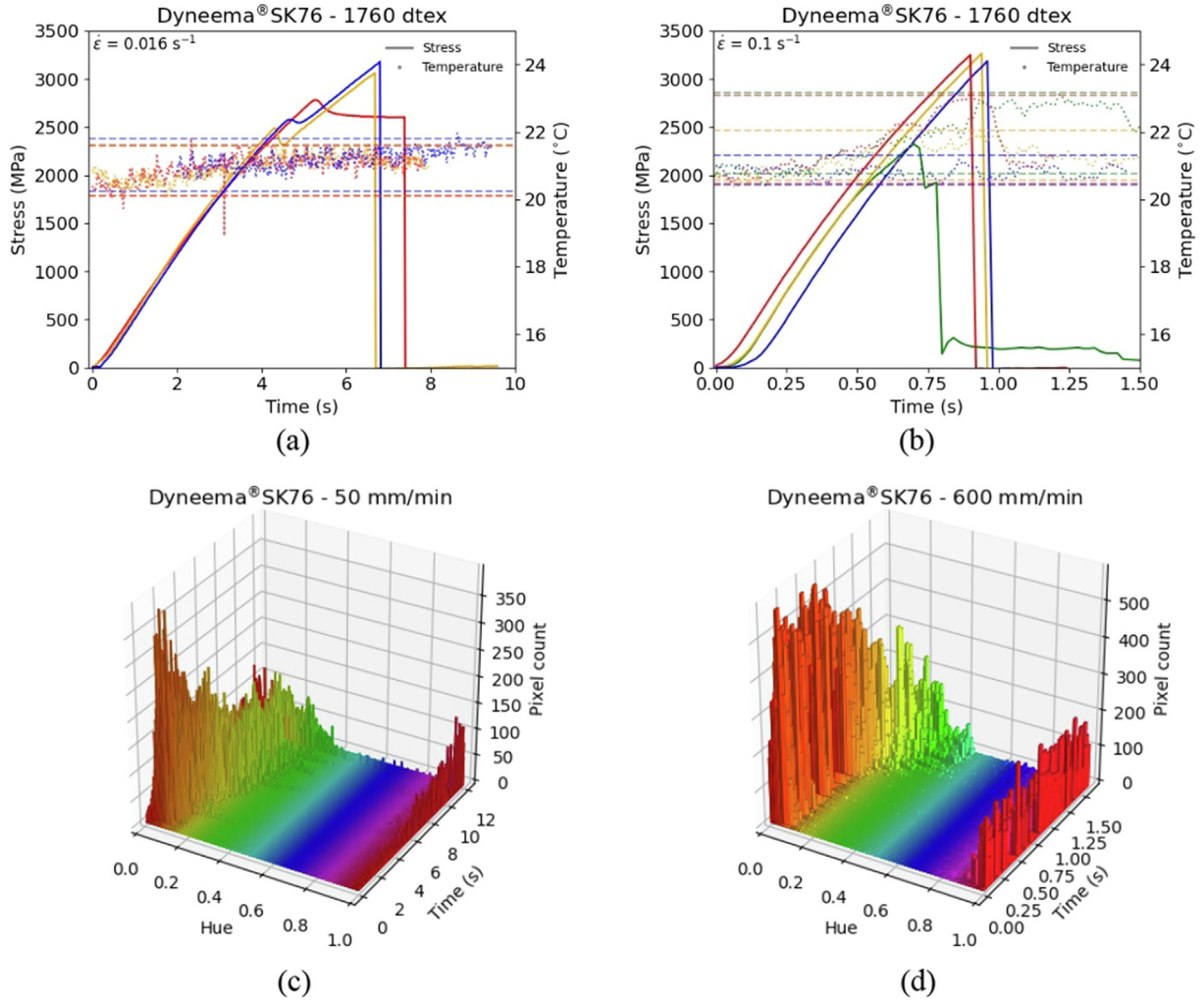

Fig. 5. (a) and (b): Stress and temperature vs. time curves for Dyneema®SK76 fibres tested at different strain rates; (c) and (d): HUE values calculated for the same tests.

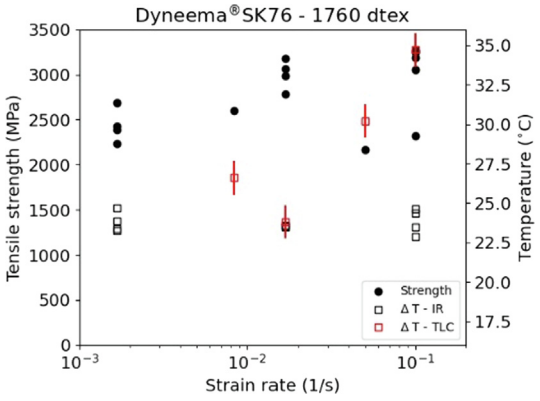

Fig. 6. Strength and temperature of Dyneema®SK76 yarn as a function of the strain rate.

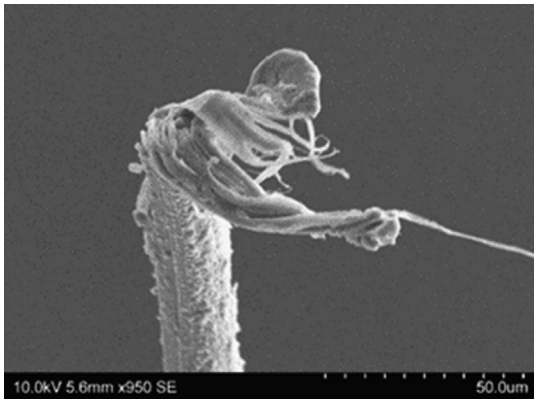

Fig. 7. SEM image of a Dyneema®SK76 filament extracted from a tested yarn.

3.2. Monotonic tensile tests on coupon specimens

Fig. 8 shows representative stress vs. time curves overlapped with temperature measurements collected during the tensile tests performed on Dyneema®HB26 laminates with different thickness. A summary of the results is presented in Fig. 9.

As observed for yarn tests, the temperature of the specimens increased as the external load increased. Analysing the results in Fig. 9, it is possible to observe that the strength of the laminates was dependent on the specimen thickness and the test strain rate. The thinner the specimen, the higher the strain rate, the higher the strength. These results are consistent with historical data for the same laminates [22]. It also appears that the maximum temperature reached during the tests was constant, within the scatter

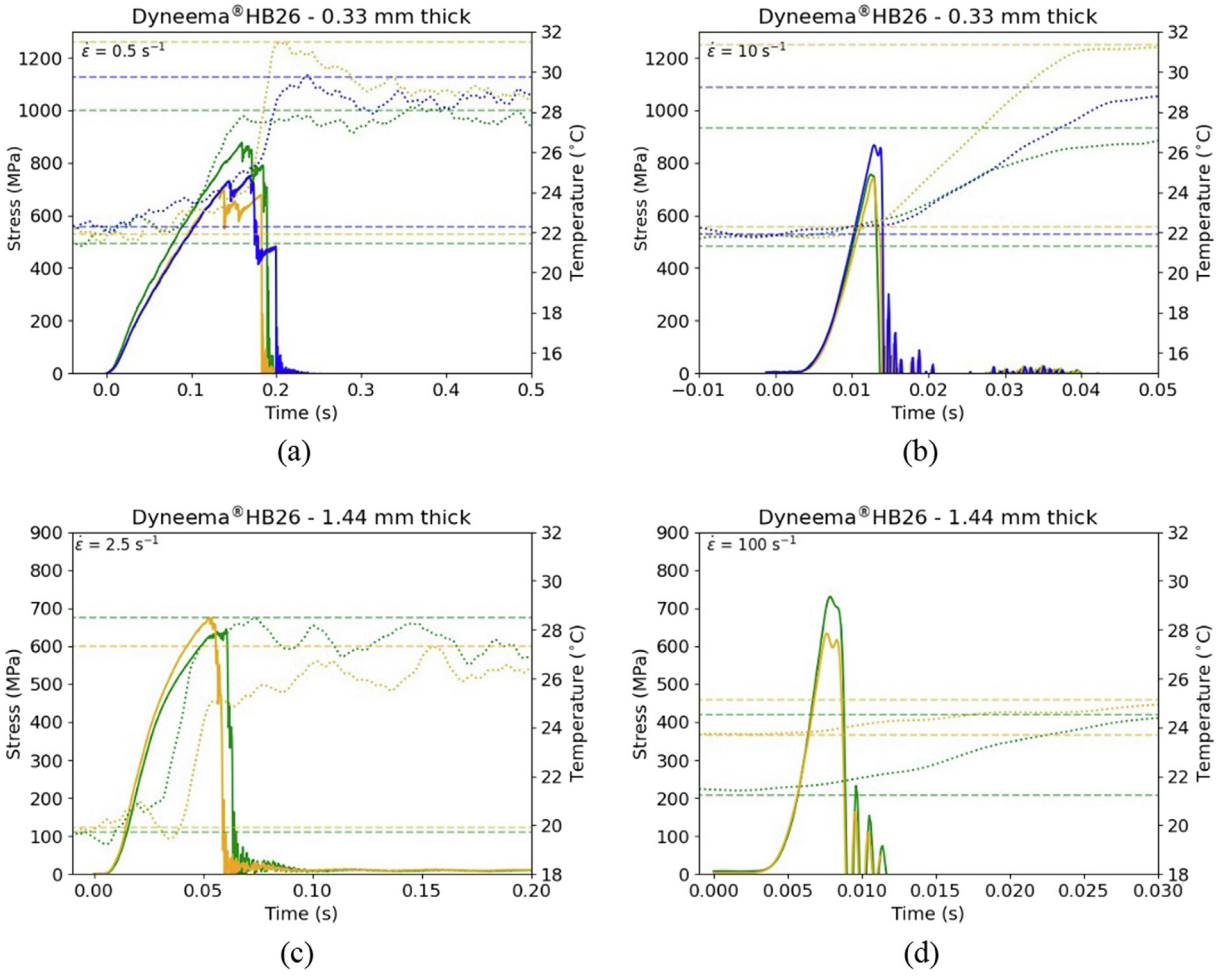

Fig. 8. Stress and temperature vs. time curves for Dyneema®HB26 laminates with different thicknesses tested at different strain rates. (a): 0.33 mm thick at 0.5 s^{-1}; (b): 0.33 mm thick at 10 s^{-1}; (c): 1.44 mm thick at 2.5 s^{-1}; (d): 1.44 mm thick at 100 s^{-1}.

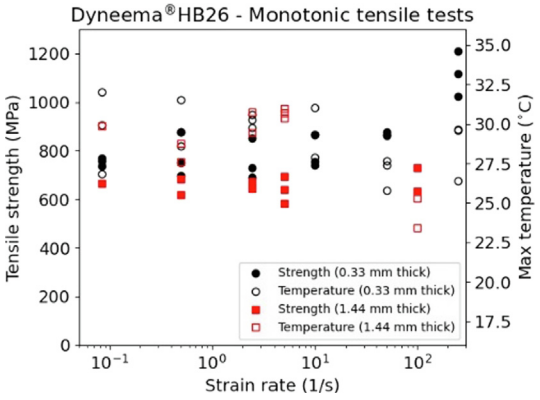

Fig. 9. Strength and temperature for Dyneema®HB26 laminates as a function of the strain rate.

error, regardless of the strain rate and the thickness of the laminate. The maximum increase in the temperature recorded during the tests was 9.2 ± 0.2 °C. The same discussions made for the yarn apply for the laminates. The lower maximum temperature recorded for the laminates could be attributed to different heat dissipation mechanisms (the laminates are resin impregnated systems, different heat absorption and dissipation mechanisms of the 90-degree layers).

3.3. Cyclic tests on coupon specimens

Coupon specimens cut from the Dyneema®HB26 laminates were also tested under fatigue loading conditions (tension–tension) to assess the fatigue life of the material as well as the specimen's temperature during the tests. Fig. 10 presents the experimental S-N curves for Dyneema®HB26 laminates tested at different frequencies, where σ_{UTS} is the ultimate tensile strength of the specimen subjected to a quasi-static monotonic load. The arrow on data at 10^5 cycles indicates that the test bottomed out, i.e. the specimen did not fail before reaching the set number of cycles.

From these results, it is possible to observe that:

- 1.44 mm thick specimens had a longer life compared to 0.33 mm thick specimens
- For both the investigated thicknesses, the higher the mean stress relative to the maximum strength, the lower the fatigue life;
- Thick specimens were able to withstand cyclic loading at higher mean stress levels compared to thin specimens; on the other hand, thin specimens were able to with-stand cyclic loading at higher amplitude stress levels compared to thick specimens;
- For the same S_a/S_m ratio, the higher the mean stress relative to the maximum strength, the lower the fatigue life, for both the investigated thicknesses;

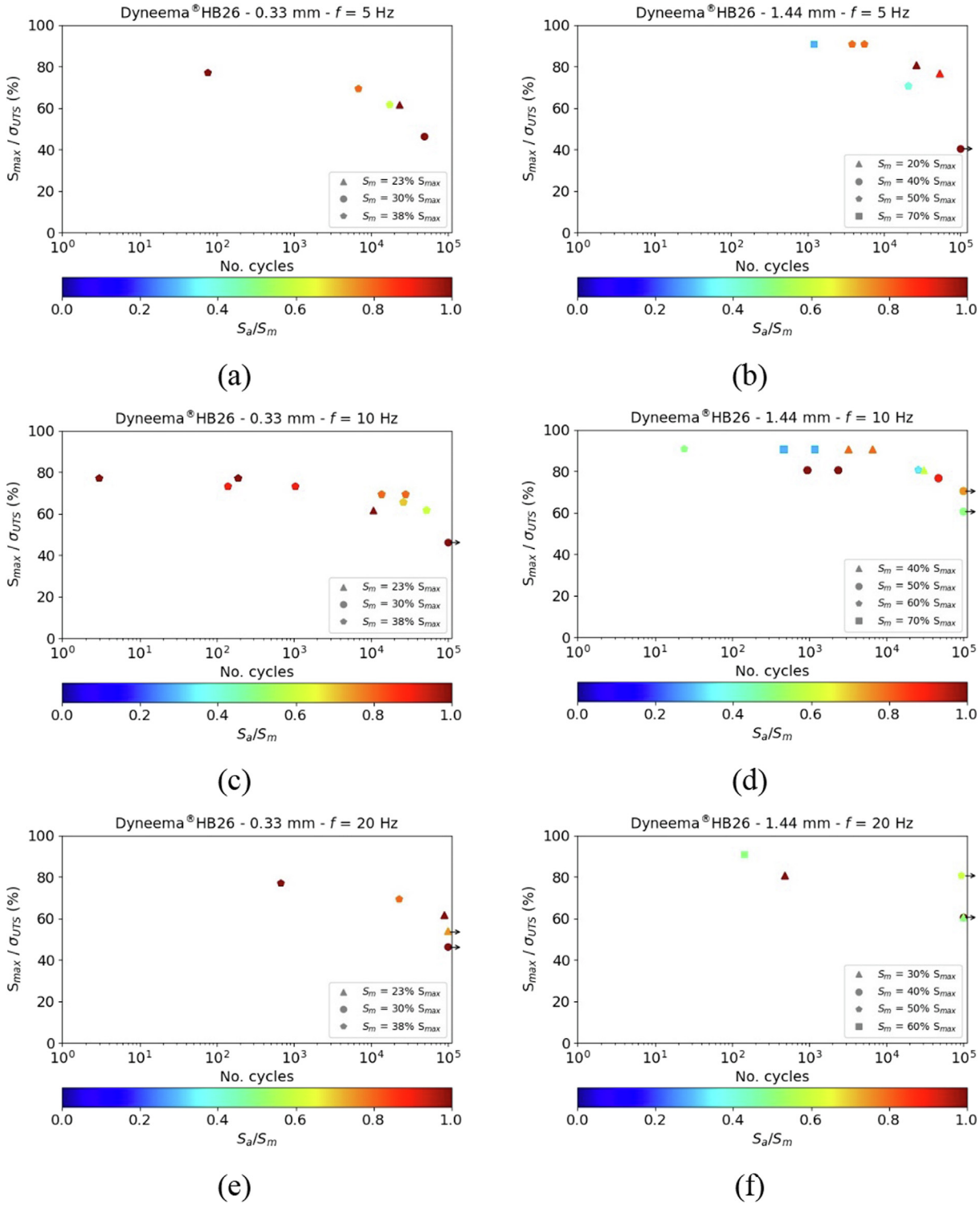

Fig. 10. S-N curves for Dyneema®HB26 laminates with different thickness tested at different frequency. (**a**): 0.33 thick mm at 5 Hz; (**b**): 1.44 thick mm at 5 Hz; (**c**): 0.33 thick mm at 10 Hz; (**d**): 1.44 thick mm at 10 Hz; (**e**): 0.33 thick mm at 20 Hz; (**f**): 1.44 thick mm at 20 Hz.

- For both the investigated thicknesses, the higher the frequency, the longer the fatigue life. At higher frequencies, the material would be stiffer and able to withstand cyclic loadings for longer times. The same conclusions were also reported in other studies [17].

The main aim of the cyclic tests was to measure the temperature of the specimen during the tests. Fig. 11 shows the evolution of the specimen's temperature during the cyclic tests performed at different frequencies for the same S_m value. Cyclic tests performed with different S_m ratios showed similar trends and not included for clarity.

It is generally observed that cyclic loading can result in material self-heating, which can lead to softening and premature failure. Analysing the collected data at the lowest investigated frequency (5 Hz), the temperature of the specimen remained fairly constant

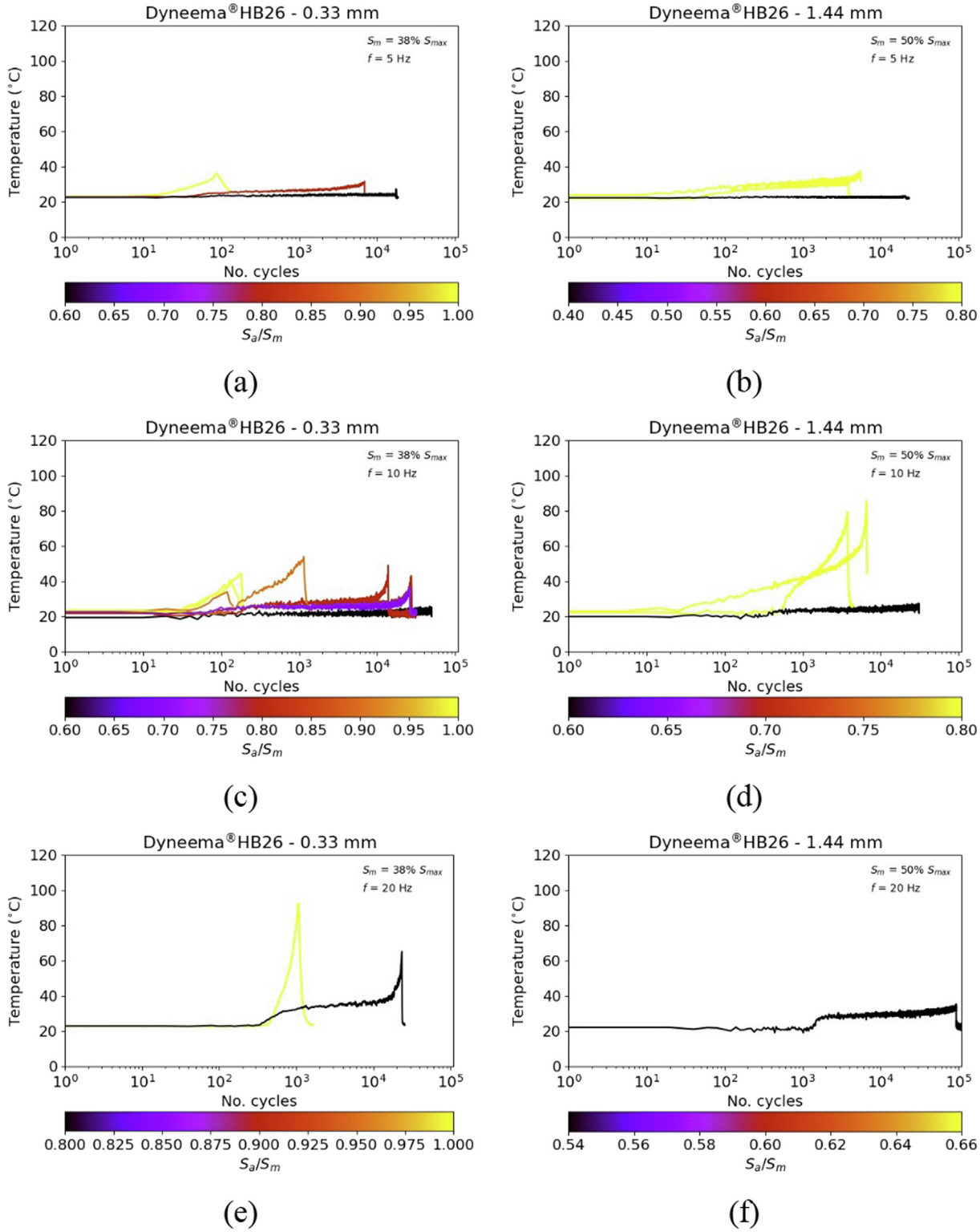

Fig. 11. Self-heating effect on Dyneema® HB26 specimens tested at different frequencies and stress amplitudes for the same S_m value. (a), (c) and (e): Thin specimens; (b), (c) and (f): Thick specimens.

throughout the test, regardless of the thickness and S_a/S_m ratio. In this region of stationary temperature, there is an equilibrium between the heat generated and the heat dissipated by the specimen in the ambient. A small increase in the temperature (up to 15 °C) was observed near the end of the test as a result of an increased damage in the specimen (mainly due to the formation of microcracks and delamination which amplifies the frictional contact of the fibres) [25]. At a test frequency f = 10 Hz, it is possible to observe that the self-heating effect was stationary for low R ratios, i.e. the specimen's temperature remained constant throughout the test. However, the stationary temperatures were slightly higher compared to those measured for tests performed at

f = 5 Hz. A significant increase in the temperature was observed near the end of the tests when the damage in the specimens grew (up to 48 °C). However, for S_a/S_m ratios higher than 60%, the heat generated became non-stationary, i.e. the temperature kept increasing with increasing the number of cycles. Moreover, the thicker the specimen, the more evident was this effect with maximum ΔT up to 73 °C. This finding can be justified by the higher degree of damage mechanisms (for example delamination, matrix cracking and plastic work) developing in thicker specimens compared to thinner ones, The trends observed for the tests performed at f = 20 Hz were similar to those seen at f = 5 Hz and 10 Hz. However, the measured stationary temperatures were higher as well as the maximum measured ΔT (up to 83 °C) compared to those measured for lower frequencies. Fig. 12 presents the overall results obtained from the testing campaign.

From these plots, it is possible to draw some conclusions.

- The maximum ΔT for thin laminates was 69 ± 1 °C;
- The maximum ΔT for thick laminates was 83 ± 1 °C;
- Even if thick laminates experienced more severe self-heating effects, they had longer cyclic life compared to thin specimens;
- Most evident self-heating effects were noted for S_m = 40% S_{max} and R = 1 for thick laminates;
- The higher the frequency, the higher the stationary temperature of the specimen, and the higher the maximum temperature before failure.

4. Discussions

Generally, the self-heating effects can lead to two possible scenarios. If the temperature remains fairly constant throughout the test, the specimen's temperature remains stationary and the final failure of the specimen is mechanical (for example crack growth and propagation, increasing damage leading to failure, delamination). The rise in the temperature would be mainly attributed to friction between the constituent materials. The other possible scenario occurs when the specimen is not able to dissipate the generated heat via convection or radiation and the temperature exponentially increases up to when final failure occurs. In this case the effect is defined as non-stationary and thermal effects are the main phenomena leading to the specimen's failure. The dominant effect that the specimen will manifest will depend on the testing parameters (frequency, stress amplitude, mean stress, environmental temperature) and material properties (specific heat capacity, conductivity, specimen geometry), and whether cooling is available. Various researches showed that air cooling significantly lengthen the fatigue life of the specimens [1,26]. Katunin and Wachla [26] experimentally showed that the fatigue life of glass/epoxy specimens could double if a suitable air flow rate is selected.

Using the procedure described in [2,27], it is possible to predict, with a good degree of accuracy, the mean amplitudes above which the specimen will experience non-stationary temperature rise. Fig. 13a shows the procedure adopted to extrapolate the stress amplitude limit for each investigated frequency, which is taken as the intersection point between the two straight lines. These results confirm that the material would have a shorter fatigue life when subjected to alternating loads at higher frequencies and higher amplitude stresses. Fig. 13b, which presents the overall results, confirmed that thin specimens were able to withstand cyclic loading at higher amplitude stress levels compared to thick specimens before the self-heating effect become dominant. It also appears that thin specimens were able to dissipate the generated heat more efficiently compared to thicker specimens. Hence, in order to avoid a non-stationary increase in temperature for a specific loading frequency, it is recommended to use the material below the stress amplitudes presented in Fig. 13b, unless cooling is employed. Additional tests are needed to refine the trends and reduce the measurement's error.

4.1. Fractographic observations of failed specimens

Selected failed specimens were sputter coated with a thin layer of gold and the fractured area inspected with a scanning electron microscope (SEM – Hitachi S-3700 N) to assess the damage occurred due to the cyclic loading. Fig. 14 shows representative images of thin and thick failed specimens with mechanical and thermal failure, respectively.

Fig. 14a and Fig. 14b present images of a thin specimen, taken at different magnifications, with a typical fatigue failure. In these images, it is possible to observe the extensive wear and fibre axial splitting. The maximum measured temperature before failure was 40 ± 1 °C. There is no clear evidence of thermal failure but only thinning and drawing at the ends of the filaments, which resulted from the softening occurred due to the external load and the temperature increase. Fig. 14c and Fig. 14d present images of a thick specimen, taken at different magnifications, with a representative

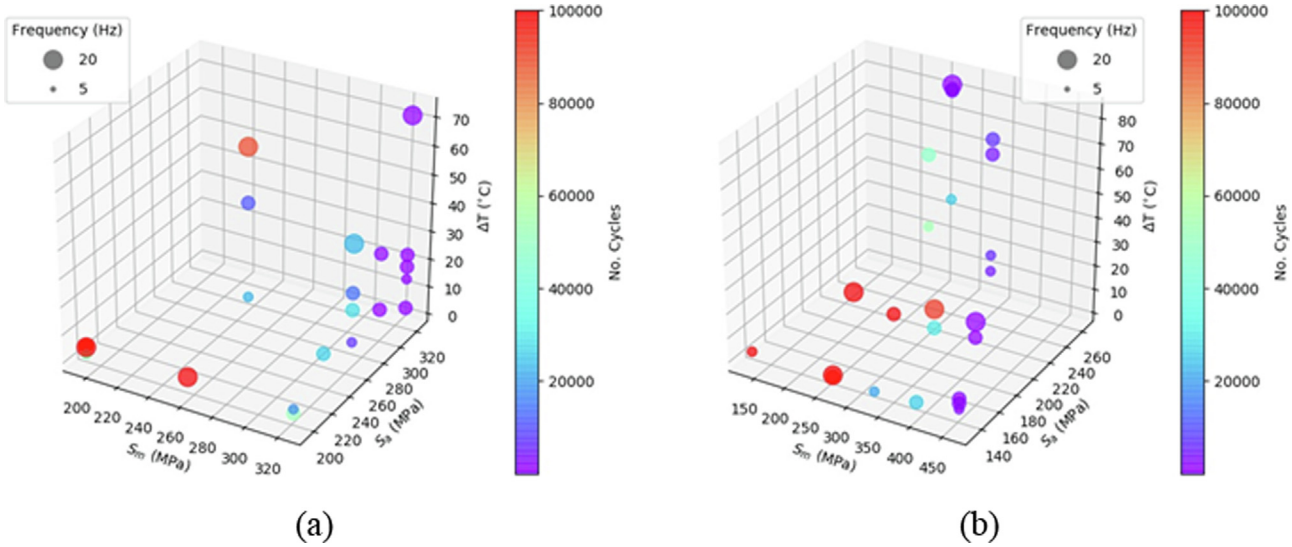

Fig. 12. Self-heating testing campaign – overall results. (a): Thin specimens; (b): Thick specimens.

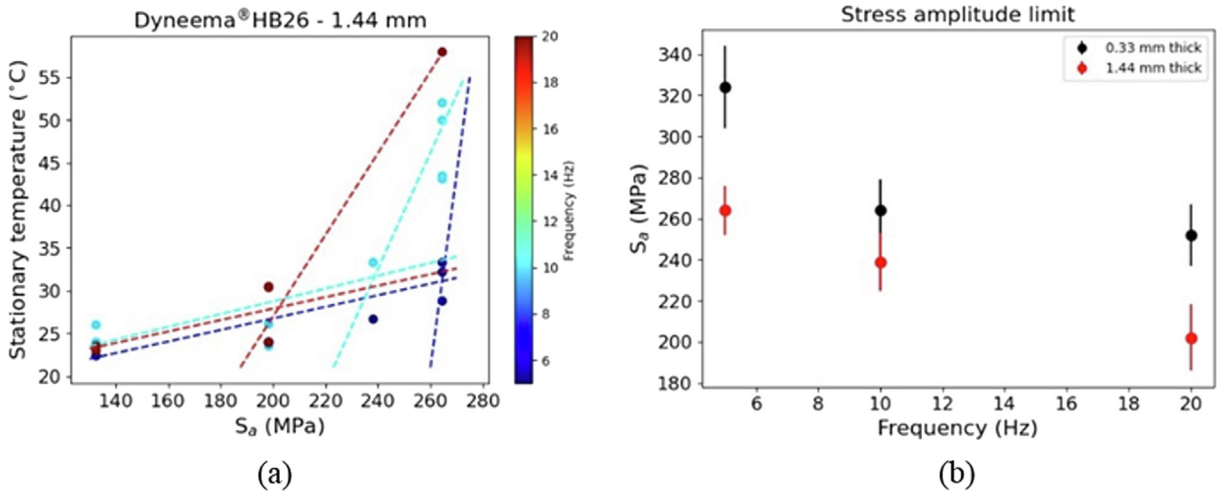

Fig. 13. (a): Determination of stress amplitude fatigue limit for 1.44 mm thick specimens; (b): Summary of the stress amplitude fatigue limits for the investigated specimens.

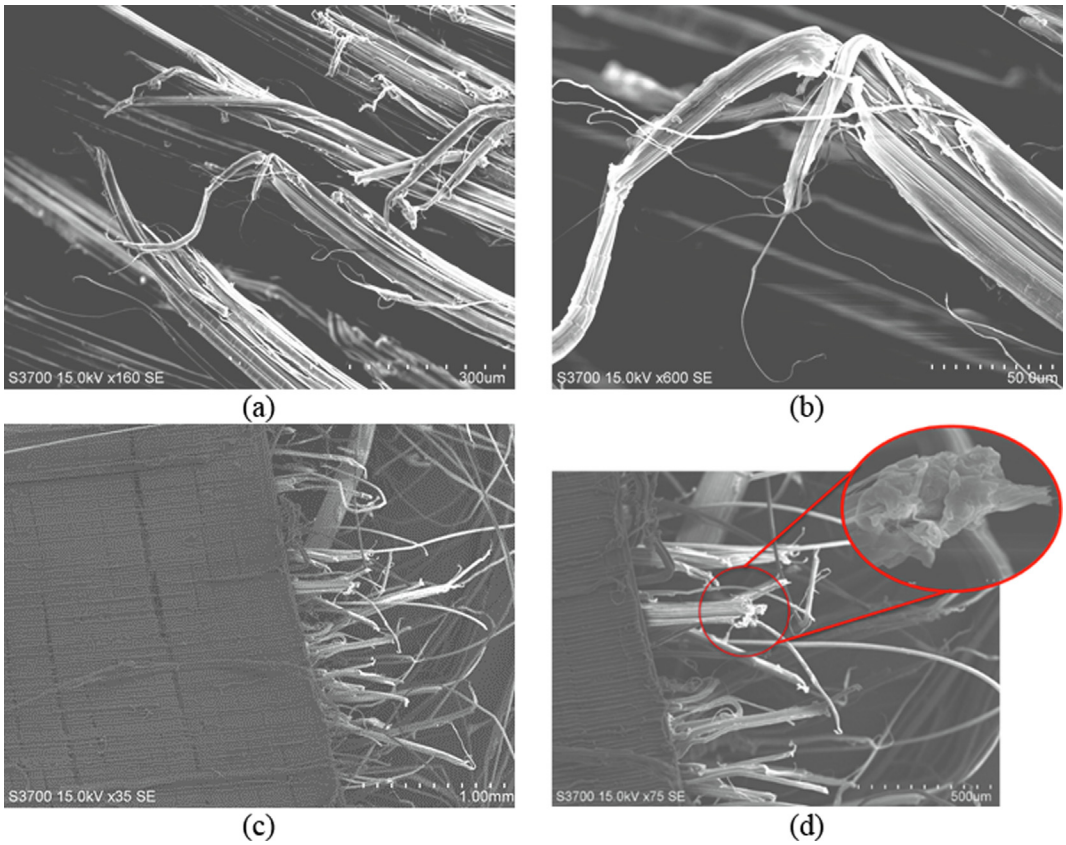

Fig. 14. SEM images of failed Dyneema® HB26 specimens. (**a**) and (**b**): Thin specimen at different magnifications tested with $S_a/S_m = 1$, $S_m = 78\%\ S_{max}$; (**c**) and (**d**): Thick specimen at different magnifications tested with $S_a/S_m = 1$, $S_m = 40\%\ S_{max}$.

type of thermal failure. In these images, it is not possible to observe wear damage in the fibres. Moreover, there was little axial splitting and fibrillation. However, the ends of the filaments were mushroomed with a granular topology which is a common feature of thermal failure in polymer fibres [28]. The maximum measured temperature before failure was 102 ± 1 °C, which is close to the melting temperature of the filaments. At high temperature, the mechanical properties of the fibres, and hence those of the composite, significantly reduce due to softening. The failure mode depended on the testing conditions:

- For $40\% < S_a \,/\, S_m > 60\%$, fatigue failure was predominant;
- For $40\% \geq S_a \,/\, S_m \leq 60\%$, thermal failure was predominant.

As previously mentioned, thicker specimens experienced significantly higher temperatures compared to thinner specimens. Nevertheless, they had a longer fatigue life when subjected to the same cyclic loading conditions. This would imply that thermal effects are not the main cause of the specimens' failure whether non-stationary self-heating effects become dominant.

5. Conclusion

This study investigated the self-heating effects occurring in Dyneema® SK76 fibres and in Dyneema® HB26 composites. A series of mechanical tests (mono-tonic tensile tests and load-controlled tension–tension fatigue tests) were carried out at different strain rates, frequencies, mean stress, amplitude stress and specimen thickness. Measurements of the surface temperature were carried out using a thermochromic liquid crystal paint and an infrared sensor. Experimental results revealed that:

- Fibres and laminates subjected to monotonic tensile loads experienced an increase in temperature. Although localised softening and melting was observed in the fibres, the maximum raise in temperature experienced by the specimens was 13.2 ± 0.2 °C when subjected to the highest strain rates.
- Fatigue tests performed on the laminates revealed a strong dependency of the fatigue life on the testing conditions.
- Tests performed at $40\% \geq S_a / S_m \leq 60\%$ revealed a significant heat generation which led to thermal failure. The maximum surface temperature measured before failure was 102 ± 1 °C. For other S_a / S_m ratios, mechanical failure was predominant.
- Stress amplitude limits, above which thermal effects became significant and the temperature rise in the specimen become uncontrolled, were determined at different frequencies for specimens with different thickness.
- When designing with UHMWPE, the design engineer should consider that the fatigue life of the part could be detrimentally affected by alternating loads at higher frequencies and amplitudes. The dissipation of self-generated heat via external cooling would be necessary to lengthen the fatigue life of engineering parts made of UHMWPE.

6. Data availability

The datasets used and/or analysed in this study are available from the corresponding author on request.

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CRediT authorship contribution statement

Stefano Del Rosso: Conceptualization, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Lorenzo Iannucci:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Dimitrios Kempesis:** Conceptualization, Writing – original draft, Writing – review & editing. **Paul T. Curtis:** Conceptualization, Writing – review & editing. **Phillip W. Duke:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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