



Short Communications

Effects of repetitive bending on cross-sections of bonded woven fabrics

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This study has been aimed at investigating the visual effects of repetitive bending of bonded textile fabrics. Cotton, polyester and cotton-polyester blend fabrics have been bonded with 3 different adhesives, namely EVA based hotmelt, copolyamide based hotmelt, and PVA based adhesives. All fabrics are bonded at $140\pm 5^\circ\text{C}$ for 20 s and then exposed to repetitive bending process for 6 h. The warp cross-sections of these samples are compared along with the investigation of visual effects of bending. Minor effects on warp cross-sections views of bonded fabrics are observed. These minor effects could explain the decrease in bonding strength of fabric-adhesive joint after the repetitive bonding process.

Keywords: Bonded fabrics, Cotton, Polyester, Repetitive bending, Woven fabric

Bonding and welding are common non-stitch joining methods for textiles. The studies on non-stitch bonding methods are generally focused on welding and its performance improvements¹⁻⁶. Commonly in non-stitch bonding, different materials are used. For this purpose, many researches have been made on organic photovoltaic panels with textiles⁷ and for wearable electronics production⁸. Although it is stated that with the increase in ultrasonic welding speed, the bonding strength decreases¹, some studies are indicating that this decrease is not statistically significant³. Washing process negatively affects the ultrasonic welding bond strength¹. In the ultrasonic welding process, while the best strength is obtained at medium speed in blended fabrics, a stronger bond is obtained at high speed in 100% cotton and polyester samples⁶. Dyeing also affects ultrasonic welding strength; higher strength is observed in the samples dyed as yarn⁹. It was emphasized that mainly the adhesion process in bonded fabric joints includes mechanical locking, and fabric hairiness affects the bond strength¹⁰. The strength of

the bonded joint is significantly affected by the type of fabric⁷. It has been observed that higher strength is obtained with synthetic yarns¹¹. It has been found that bonding joints in garments are constantly exposed to bending, twisting, buckling, and tensile stresses; and as the exposure time increases, the bond strength decreases rapidly at first and then the rate of decrease gets lower¹¹. This study is purposed to investigate these declines in joint strength via SEM images. The major visual difference before and after this repetitive bending exposure is also studies.

Welding and bonding have certain advantages like fast production, sealing or ease to create a pattern, etc. The studies on welded and bonded textiles generally include the process parameters effects and strength of the joints. However, the performance of these fabrics' joints should be maintained for their lifetime. For a better understanding of these fabrics' performance, long-term effects need to be examined. Generally, textiles have high resistance to bending deformation under small force. However, the bending deformation behaviour of the adhesives may be different. For this reason, bonded fabric bending behaviour could be different from the unbonded fabric's bending behaviour.

There are many studies on the bending behaviour of fibres and fabrics. Veer¹² declared that bending fatigue of synthetic fibres did not cause problems in apparel fabrics, except pilling. Natural fibres have also good resistance to bending fatigue, except for linen and regenerated cellulose fibres¹². Cai *et al.*¹³ used a mechanism to test the bending fatigue of aramid fibres. It was found that the Kevlar 49 fibre can be easily ruptured at a large bending angle and pretension. There is a linear relationship among the pretension, bending angle, and the logarithmic value of fatigue lifetime¹³. In another study, the effects of fabric sett on bending behaviour of viscose/polyester blended woven fabrics were investigated¹⁴. Their bending behaviour was tested with Kawabata, the extraction method, and the concentrated loading method. It is observed that each fabric, depending upon its density, would have different types of deformation; while fabric density increases, the buckled zone shape of the fabric goes toward the rounded curvature shape¹⁴. Arsoy¹¹ showed the stress distribution in bonded textiles exposed to

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bending. While bending, there is tension on the outer surface of the joint and compression on the inner surface of the joint. When the bending direction changes, the forces affected the fabric and adhesive layers reverse (tension to compression and compression to tension). It can be said that the strength decreases in bonding joints exposed to bending are caused as a result of weakening of the adhesive layer due to the effects of these two forces¹¹. In this study, it is aimed to detect a visual effect of this weakened adhesive layer. Cotton, polyester, and cotton-polyester blend fabrics are bonded with 3 different adhesives. After 6 h repetitive bending processes, the cross-sections of these samples are compared. The SEM images of bonded fabrics before and after bonding are compared.

Experimental

Materials

Cotton, polyester, and cotton/polyester blended woven fabrics were used. The technical parameters of the sample fabrics are given in Table 1. Different types of adhesives were used. Two of them were hotmelt adhesives (A1 and A2) and the other one was liquid. The technical parameters of the adhesives were given in Table 2.

EVA based hot melts are commonly used for cellulosic materials. They usually consist of 30-40% EVA copolymer, 30-40% tackifier resin, 20-30% wax, and 0.5-1% stabilizer¹⁵. Copolyamide based hotmelt adhesives usually consist of dimer acid containing two or more different diamines. Dimer acid is composed of 60-80% of the total mass and provides an amorphous non-polar character. The existence of hydrogen bonds between polymer chains provides strength. Polyvinyl acetate (PVA) is an

aliphatic synthetic polymer from the polyvinyl ester family and is used for bonding porous materials (paper, fabric, wood, etc.).

Bonding Process

A1 and A2 are hotmelt film adhesives and A3 is liquid. All fabrics are bonded at $140\pm 5^\circ\text{C}$ for 20 s and on an area of $3\times 2\text{ cm}^2$. Film adhesives are used as a single layer. A3 adhesive is used in $0.025 \pm 0.001\text{ g/cm}^2$. Bonded fabric samples are given in Fig. 1.

Repetitive Bending

Bonded fabrics are usually exposed to bending, buckling, and stress deformations. Arsoy¹¹ designed a test device to evaluate the bonded fabric behaviour under these kinds of deformations. The basic working principle of the designed test device is given in Fig. 2.

The sample fabric is set between 3 and 4 jaws. Jaw 3 is fixed while unfixed jaw 4 regulates the fabric tension by a spring mechanism (9 and 10). The roller (2) forces the fabric to bend unidirectionally. The device works with 277.78 bendings/min speed and applies 100,000 bendings in 6 h. The pretension is set as 1.2 N. Also, portable jaw grip 4 causes tensile stresses on the vertical direction of sample. All the samples are chosen in warp yarn direction.

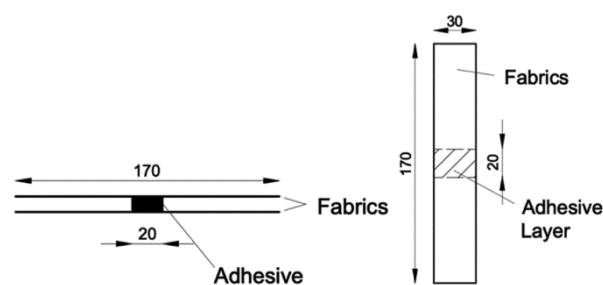


Fig. 1 — Bonding of fabrics

Table 1 — Technical parameters of sample fabrics

Sample code	Sett		Fabric weight g/m^2	Woven design	Fibre content (Cotton/polyester)
	Weft	Warp			
F1	18	20	180	Plain	35/65
F2	36	50	125	Hopsack	60/40
F3	33	58	110	Plain – twill combined	50/50
F4	24	44	200	Twill	100/0
F5	36	38	50	Plain	0/100

Table 2 — Technical parameters of adhesives

[Curing-thermal, bonding process parameters: temp. $140\pm 5^\circ\text{C}$, time 20 s]

Sample code	Chemical content	Form	Weight, g/m^2
A1	Ethyl vinyl acetate (EVA) based hotmelt	Film	20
A2	Copolyamide based hotmelt	Film	60
A3	Polyvinyl acetate based	Liquid	-

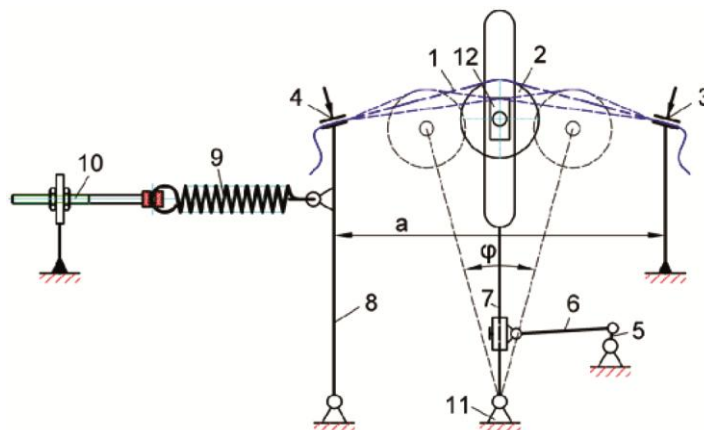


Fig. 2 — Working principle of designed test device¹¹

SEM Analysis

Bonded fabrics are examined according to their warp cross-sections. Cross-sections of bonded fabrics before and after repetitive bending deformations were investigated. SEM images were taken 36 h after bonding and repetitive bending. All samples were coated with a gold layer for analysis.

Results and Discussion

Cross-sections of bonded fabrics with A1 adhesive film is given in Fig. 3. All samples with A1 adhesive have a soft touch. There is not any unwanted visual effect on fabric surface. A1 is a very thin layer of hotmelt adhesive ($\sim 23 \mu\text{m}$), so it is easily observed that only a couple of fibre layers join the bonding area.

At F1-A1 joint, warp cross-sections are more oval after exposure of bending. On images of F2-A1 joint, F3-A1 joint and F5-A1 joint, there are no significant changes in warp cross-sections after exposure. On images of F4-A1 joint, there is a difference between two images about the contact of the adhesive – fabric interface. Fewer contact areas are seen after 6 h of the repetitive bending process. All joints have a very thin adhesive layer which causes thin bonding depth in fabric cross-section.

Cross-sections of bonded fabrics with A2 adhesive film is given in Fig. 4. All bonded fabric samples with A2 adhesive have a soft touch and show no visual unwanted effects. A thicker adhesive layer than A1 can be observed. Because A2 has three times more weight than A1, the measured thickness of A2 ($\sim 75 \mu\text{m}$) is consistent.

At F1-A2 joint, warp cross-sections are found more elliptical after exposure of bending. On images of F2-A2 joint, more elliptical warp cross-sections are seen,

especially at the bottom layer of bonded fabrics. Also, it is observed that there is a decrease in the contact between adhesive and fabrics. Likewise, this decreased contact can also be observed at F3-A2 joint, F4-A2 joint, and F5-A2 joint.

As it is shown in Fig. 5, liquid A3 adhesive penetrates into the fabric layers. Even though the adhesive penetrates into the whole fabric layer, the bonded fabrics have a soft touch and show no unwanted taints, except in case of F3 – A3 (adhesive caused stains on fabric surface). In F1 – A3 cross-section, air gaps in adhesive layers are seen. It is observed that air gaps are more often seen after repetitive bending exposure. In F2 – A3 joint, air gaps are also seen more common after 6 h exposure of bending and stress. In F3 – A3 adhesive layer, thickness is measured as 80 microns. It is slightly more than that in A2. Both before and after the exposure of bending, air gaps in adhesive layers are seen. There are no significant differences found in warp cross-sections between two images of F3 – A3. In F4 – A3 joint, it has been observed that the adhesive spreads into the gaps between yarns in the fabric. After repetitive bending, it is seen that the adhesive penetration into the fabric is weaker. In addition to the weaker fabric-adhesive contact, air gaps are also seen. In F5-A3 joint, it is observed that no major differences are observed in the SEM images between before and after the repetitive bending process.

The decrease in adhesive-fabric contact, which has been observed in cross-sections images of joints, may explain the decrease in strength tests of the bonded fabric. Arsoy¹¹ reported that an approximately 34% decrease in the strength of bonded fabrics is seen after 1 h of repetitive bending (60 bendings/min).

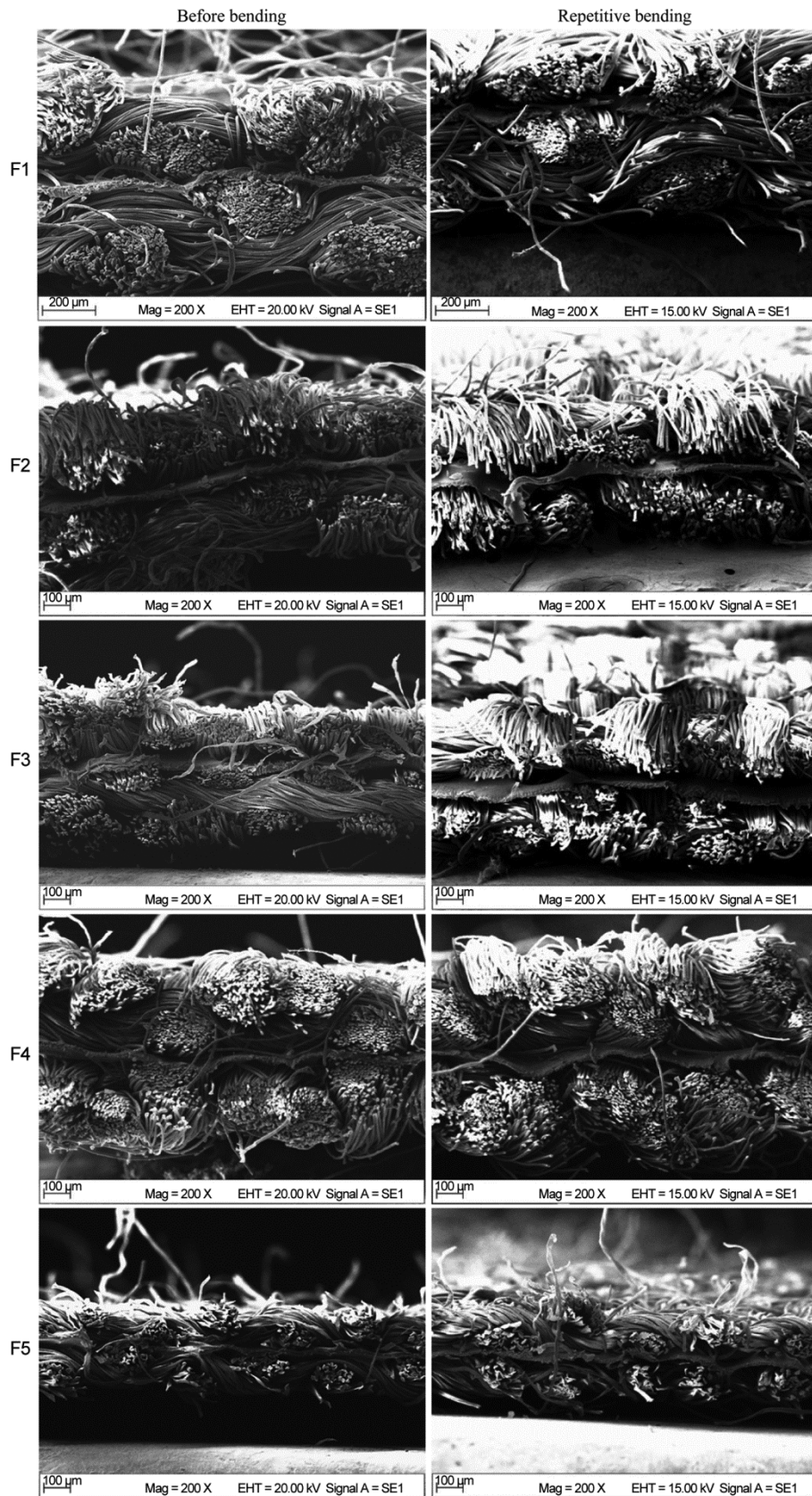


Fig. 3 — Bonded fabric cross-sections before and after repetitive bending for 6 h with adhesive A1

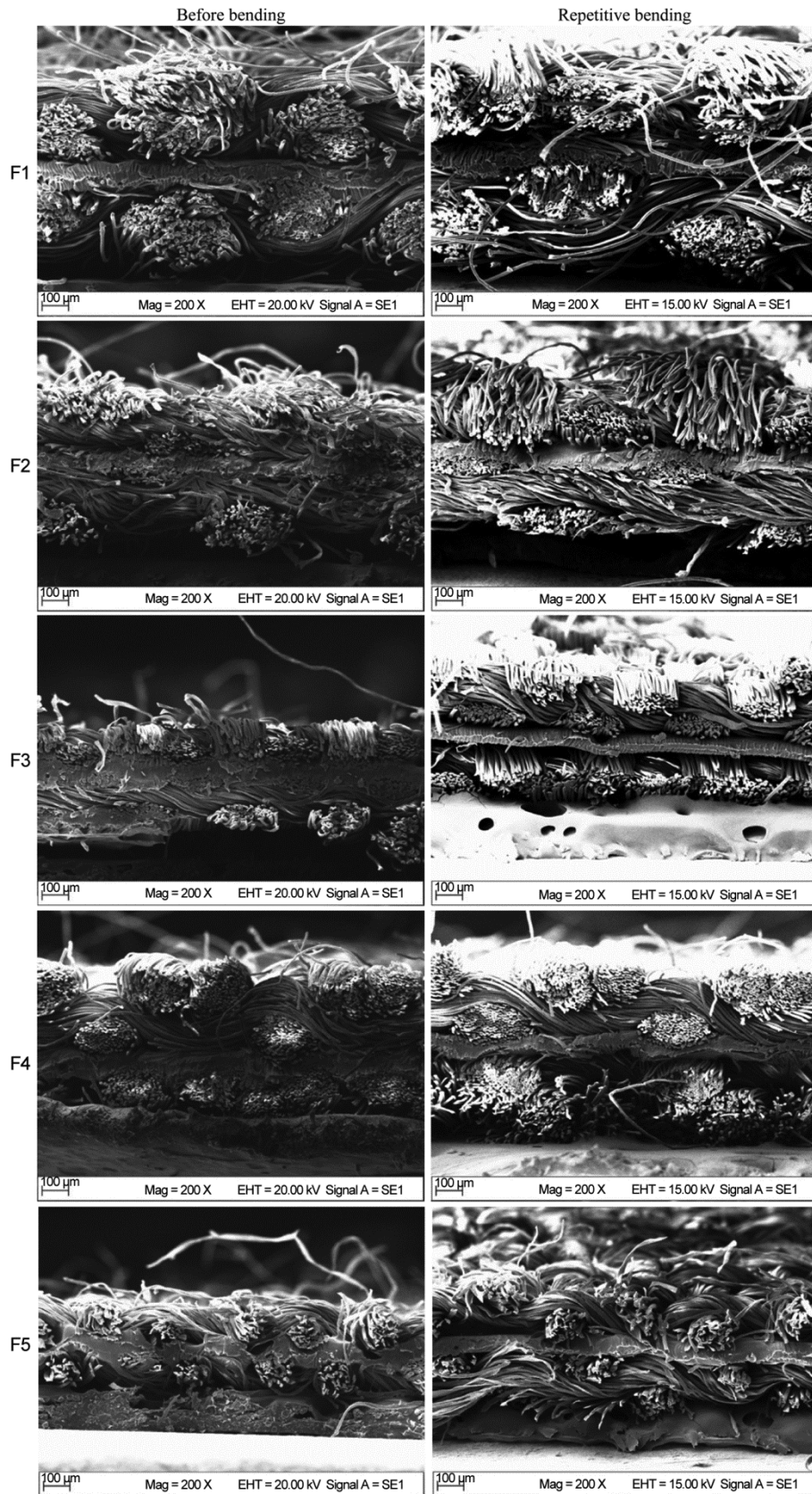


Fig. 4 — Bonded fabric cross-sections before and after repetitive bending for 6 h with adhesive A2

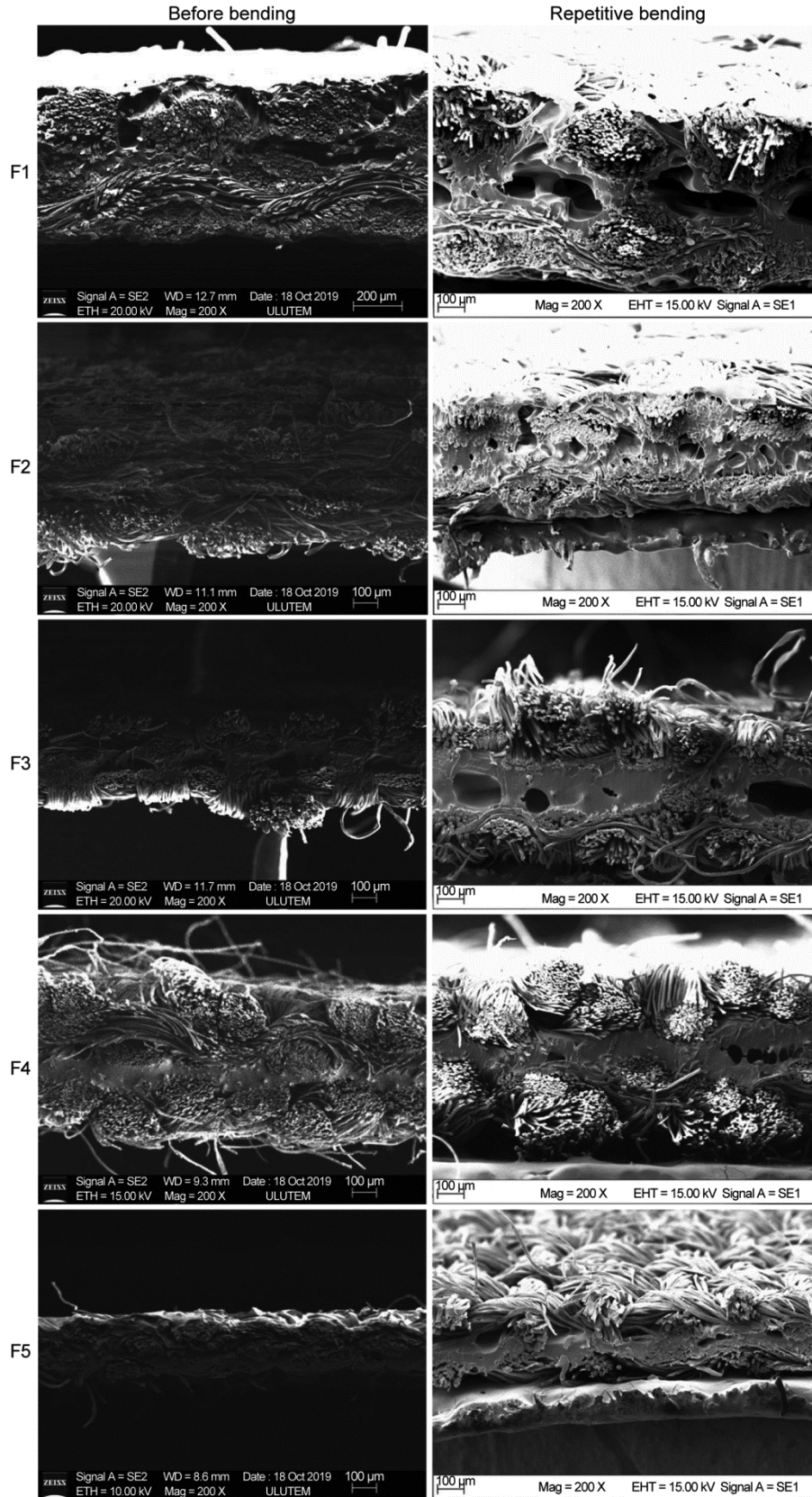


Fig. 5 — Bonded fabric cross-sections before and after repetitive bending for 6 h with adhesive A3

Both the fabric and adhesive layers can be seen clearly in SEM images. Thermoplastic film adhesives are thin layers so they remain on the inner surface of fabric layers instead of penetrating through fabric depth. All adhesives create soft joints and do not cause major changes in appearance. Although it is determined that the warp cross-sections after the bending of some samples are more oval, there is no significant difference, in general. As a result of the SEM analysis, the following observations are made:

- There are no major differences in cross-sections of samples (especially with thermoplastic adhesive films) before and after the bending process.
- At some joint, the contact of the adhesive-fabric layer decreases after 6 h of repetitive bending.
- At A3 adhesive's cross-section images, more air gaps are found after the bending process. This may be related to the bending process or bonding process itself.

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