M. R. Ahmad, M. H. M. Yahya[1)], *M. R. Hassan, J. Salleh, W. Y. W. Ahmad, N. Hassim

Faculty of Applied Sciences, Universiti Teknologi MARA,
Shah Alam, Selangor, Malaysia

***Faculty of Engineering, Universiti Putra Malaysia,**
Serdang, Malaysia
[1)]Corresponding author: harris_6556@yahoo.com

Production of Shape Memory Alloy Core-Sheath Friction Yarns

Abstract
This paper describes some studies on the development of shape memory alloy (SMA) core-sheath friction yarns. SMA wires for actuating purposes were utilised as a conductive element in the core-sheath friction yarn. A DREF 3000 friction spinning machine was used to produce the yarns. The conductive yarn was spun with the SMA actuator wire at the core and 100% cotton fibers in the second layer as the sheath producing a yarn called SMA core-sheath friction yarn (SMA CSFY). During spinning, the core-sheath ratio and spinning drum speeds were varied. The main purposes of the study were to evaluate the SMA CSFY single yarn tensile strength and its actuating performance against changes in the spinning process parameters. The results showed that SMA CSFY with the highest spinning drum speed and 60% core gave the highest tensile strength and fastest actuation performance.

Key words: *shape memory alloy, DREF 3000 spinning system, conductive yarn.*

Introduction

The growing development of smart textiles is changing the point of view of world textile fashion from traditional textile products to functional and more interactive textile design products [1]. Schwarz et al. [2] noted that smart textiles products came about from an effort to converge many disciplines such as wireless and mobile telecoms, microsystems and nanotechnology, advanced material technology, biology, physics, chemistry, electrical engineering, and textile. The many advantages of smart textiles are the generation of new ideas for engineers and designers such as imparting textile substrates with a lighting device [3], thermochromic properties [4], health-care monitoring device [5], a soft antenna system for military usage [6] and phase change properties [7].

The phases of change properties in SMA have made it mainly used for sensing and actuating. SMA provides a superelastic and shape memory effect. It is manufactured in various forms such as a bar, ribbon, thin or thick sheet, hollow rod wire and thin or thick wire. Among others, thin SMA wires are most suitable to be incorporated into a textile substrate, especially in the form of yarn that tends to be electrically conductive and have a shape memory effect. The embedding technique is a suitable method of combining thin SMA wire into a yarn and the technology proposed to be used is the DREF 3000 friction spinning system.

The DREF spinning system was introduced in the early 1970s and is capable of spinning a medium to course yarn sizes. It is also capable of processing natural and synthetic fibres from 32 to 60 mm in length [8]. Technically fibres from a card sliver are opened into individual fibres. The opened fibres (reduced size fibres) are then transfered onto the spinning drums, which are rotating in the same direction with the assisstance of an air stream system located at the top of the spinning drums. Either one or both of the drums are rotated and have a suction arrangement inside them to prevent fibre slippage while the fibres are twisted on the drums. The yarn is formed by frictional forces between the fibres and surfaces of the rotating spinning drums and is drawn-off at a right angle to the direction of the moving surface. Since the drum's diameter is many times higher than the yarn diameter, each revolution of the drum imparts a large number of twist to the yarn [9].

The DREF 3000 is another version of the DREF spinning system. It has an additional drafting system at the side of the spinning zone that is for the insertion of the core sliver for yarn structure stability, increasing the yarn strength and imparting any functional fibre to the yarn produced. ***Figures 1.a*** and ***1.b*** illustrate the cross-sections and longitudinal view of core-sheath friction yarns from the DREF 2000 and DREF 3000 spinning systems. A helical core wrapper means the yarn is produced with a twist given at a certain angle and direction ('S' or 'Z' direction). Meanwhile a parallel core wrapper means the core sliver has been given a twist at first at the first drafting unit and then false twisted when entering the spinning zone.

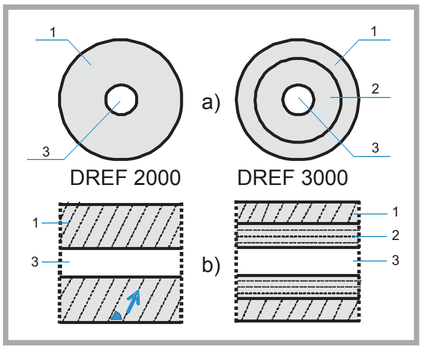

Figure 1. *a) Yarn cross-section and b) yarn longitudinal view from DREF 2000 and DREF 3000. 1) Sheath fibre (Helical core wrapper), 2) Core fibre (Parallel core wrapper), 3) Strengthening or functional purpose (Core component).*

Many works have been done to embed electrically conductive and smart material into the core of spun yarns [10 - 18]. Some researchers reported on the spinning of conductive core-sheath friction yarn by utilising stainless steel or copper wire as a conductive core for applications such as electrical conducting and electromagnetic sheilding effectiveness [14 - 16]. In another study, Kumar et al. [17] reported on the utilisation of plastic optical fibre as an optical core for signal transferring fabric. Another study by Hassan et al. [18] reported on the utilisation of carbon filaments in the core and some investigations on yarn electro-mechanical properties. Jing and Hu [19] reported on the production of shape memory core spun yarn by utilising shape memory polyurethane as a smart material in the core. The present study aims to examine the production of SMA core-sheath friction yarn (SMA CSFY) using the DREF 3000 spinning system. SMA CSFY yarn shows special characteristics like electrical conductivity and the shape memory effect in comparison to other categories of conductive yarn. SMA CSFY yarn's tensile strength and actuation performance are discussed in this paper.

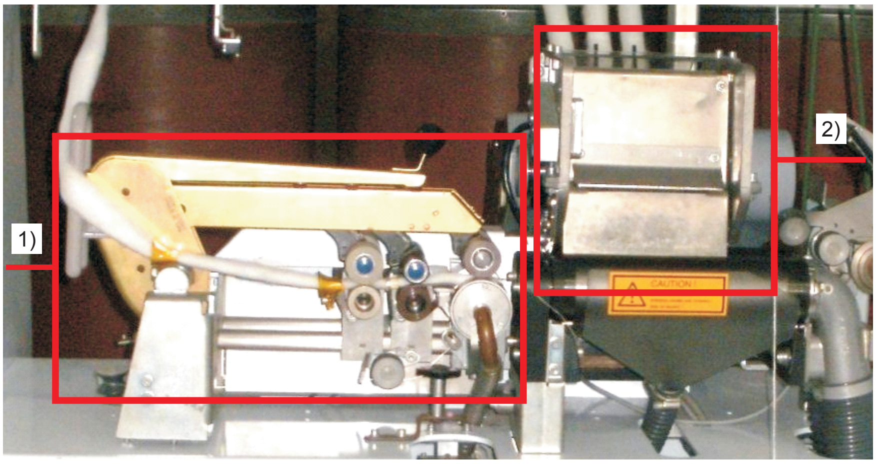

Figure 2. Location of the: 1) 1st and 2) 2nd drafting unit of the DREF 3000 spinning system.

DREF 3000 principle of operation

As previously mentioned, the DREF 3000 friction spinning system differs from the DREF 2000 because it is comprised of another drafting unit for core sliver insertion. Aydogmus et al. [20] classified both the drafting unit on the DREF 3000 spinning system as a first drafting unit and second drafting unit. ***Figure 2*** illustrates the location of the first and second drafting unit. In the system, 1 to 6 carded slivers can be inserted as sheath slivers into the second drafting unit. Only one carded sliver is required to be inserted into the first drafting unit, which will be drafted in order to fit into the core of the yarn. A small amount of twist will be given to the sliver from the first drafting unit, and this sliver will be false-twisted immediately after it reaches the spinning zone. The amount of fibre supply from the first drafting unit will depend on the core-sheath ratios that have been set before the spinning process. The increasing portion of the core will lead to an increase in the speed of sliver supply from the first drafting unit. The slivers at the second drafting unit will be opened into fine individual fibres by a carding drum which is rotating at a very high speed of up to 5700 r.p.m. After going through the carding drum, the fibres will be transported to the spinning zone. The spinning zone consists of two spinning drums arranged perpendicularly to the carding drum and one or two spinning drums rotating in the same direction. In addition, the surface of the spinning drums consists of an air suction system for transporting fibres from the carding drum to the spinning zone. The high speed rotating spinning drums receive the fibres and give them a twist either in the 'S' or 'Z' direction (according to the requirement). At the same time, the core sliver will be wrapped by the twisted sheath sliver from the second drafting unit, and because the core sliver has been given a false twist, the fibre in the core position will be in parallel with the yarn axis, while the wrapper fibre will be at a helix angle.

Shape Memory Alloy (SMA) wire

SMA is a bimetallic material consisting of a combination of nickel and titanium metals. In comparison with other metals, SMA can deform to its original shape upon changes in thermal, mechanical, magnetic or electric properties occuring on it. The deformation of this wire is related to two stable phases, namely martensite and austenite [21]. Martensite is where the SMA is in a low temperature condition, while austenite is where the SMA is in a high temperature condition. In addition, each of them consists of two categories of transformation temperature: martensite start temperature (Ms), martensite finish temperature (Mf), austenite start temperature (As) and austenite finish temperature (Af). Ms refers to the temperature at which the SMA starts to transform from the austenite phase to the martensite phase. Meanwhile, As refers to the temperature at which the SMA starts to reverse from the martensite to austenite phase. Both Mf and Af refer to the temperature at which they are completely deformed into martensite and austenite phases [22]. This advantage makes it widely used as a substitution for conventional pneumatic, hydraulic and motor-based actuator systems. The fine wire form of SMA is most suitable to be used in textile applications. However, due to the stiffness and high flexible properties [21] of this wire, research on embedding SMA wire into a textile substrate is still being investigated. Besides this, the addition of a textile substrate to stiff-like but flexible wire might offer a better textile surface that is probably reliable enough to be processed in spinning machines. Further research is needed to determine the reliability of the combination of wire

Table 1. *Specific spinning process parameters.*

Spinning parameter	Spinning drum speeds, r.p.m.	Core-sheath ratios, %
1	3000	40-60
2	3000	50-50
3	3000	60-40
4	3700	40-60
5	3700	50-50
6	3700	60-40
7	4400	40-60
8	4400	50-50
9	4400	60-40

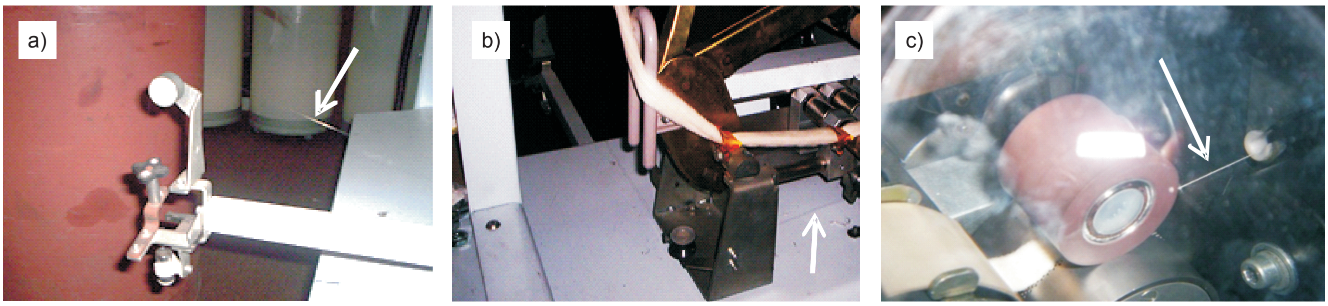

Figure 3. *a) Wire being placed on a special guide from the back of the machine, b) wire being placed on the first drafting unit using a guide roller and c) wire being placed together with the core sliver on the front roller of the first drafting unit.*

and textile substrate in terms of its specific technical and functional properties such as tenacity, material surface evenness, conductivity and electromagnetic performance.

Materials

In the study, SMA wire (Type M), manufactured by MEMRY GmbH (Germany), with a tensile strength of 17.513 cN/tex, diameter of 0.175 mm, and linear density of 130 tex was utilised as the conductive material. The wire (indicated as 'W' in the graph) was in the form of a spiral and then it was annealed. The annealing temperature was 550 °C for 20 minutes. The study used 100% cotton carded slivers as the core and sheath. Additionally 100% cotton spun yarn with a tensile strength of 8.810 cN/tex and 28 tex linear density was used to assist the spinning process. A DREF 3000 friction spinning machine was used to produce the SMA CSFY.

Methodology

SMA CSFY production

A 4.0 ktex cotton carded sliver was fed through the first drafting unit as the core sliver, while three 5.0 ktex cotton carded slivers were fed to the second drafting unit. The delivery speed and suction pressure motor speed were constantly set at

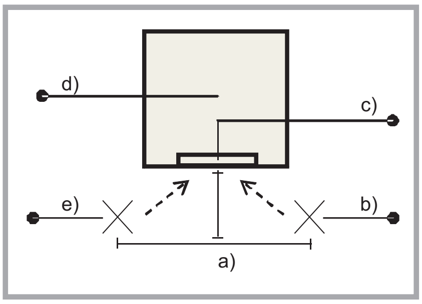

__Figure 4.__ Observation method schematic test set-up (top view); a) observation distance, b) first check point, c) glass window lead, d) memmert vaccum oven (glass window lead), e) second check point.

130 m/min and 4800 r.p.m., respectively. The spinning process was performed using several process parameters, as indicated in ***Table 1*** (see page 69).

In the preliminary stage of the spinning process, the wire was simply placed on the first drafting unit together with the core sliver. ***Figures 3.a, 3.b*** and ***3.c*** (see page 69) show the flow of wire being placed on the front drafting roller at the first drafting unit.

Single yarn strength test

A single yarn strength test of the SMA CSFY was conducted in accordance with the EN ISO 2062 standard. A 25 mm/min test speed and 0.50 N pre-tension test speed were set on the universal Testometric Tensile instrument. The specimen length for each test was 50 cm and the gauge length was set at 30 cm.

Actuating performance test

This test was done to understand the influence of sheathing the SMA wire with different machine process parameters in comparison with the SMA wire itself. The actuating performance test was conducted using a Memmert vaccum oven with a constant and controlled temperature of 130 °C for a quick yarn actuating response effect. The oven has a glass window, which enables to observe the yarn actuation process. Three persons were needed for the experiment in order to observe the actuation of the yarn, one of whom was responsible for placing the yarn in the oven, while the other two stood at the two observation check points on the right and left side of the oven to observe the yarn starting and stopping actuating. ***Figure 4*** shows the test set-up for this experiment. The SMA CSFY test yarn was cut into 20 cm specimens . Both observers immediately started the stopwatch as soon as the yarn was placed into the oven. The observer on the right started the stopwatch as the yarn started actuating. The other observer then stopped the stopwatch once the yarn stopped actuating. The difference in time

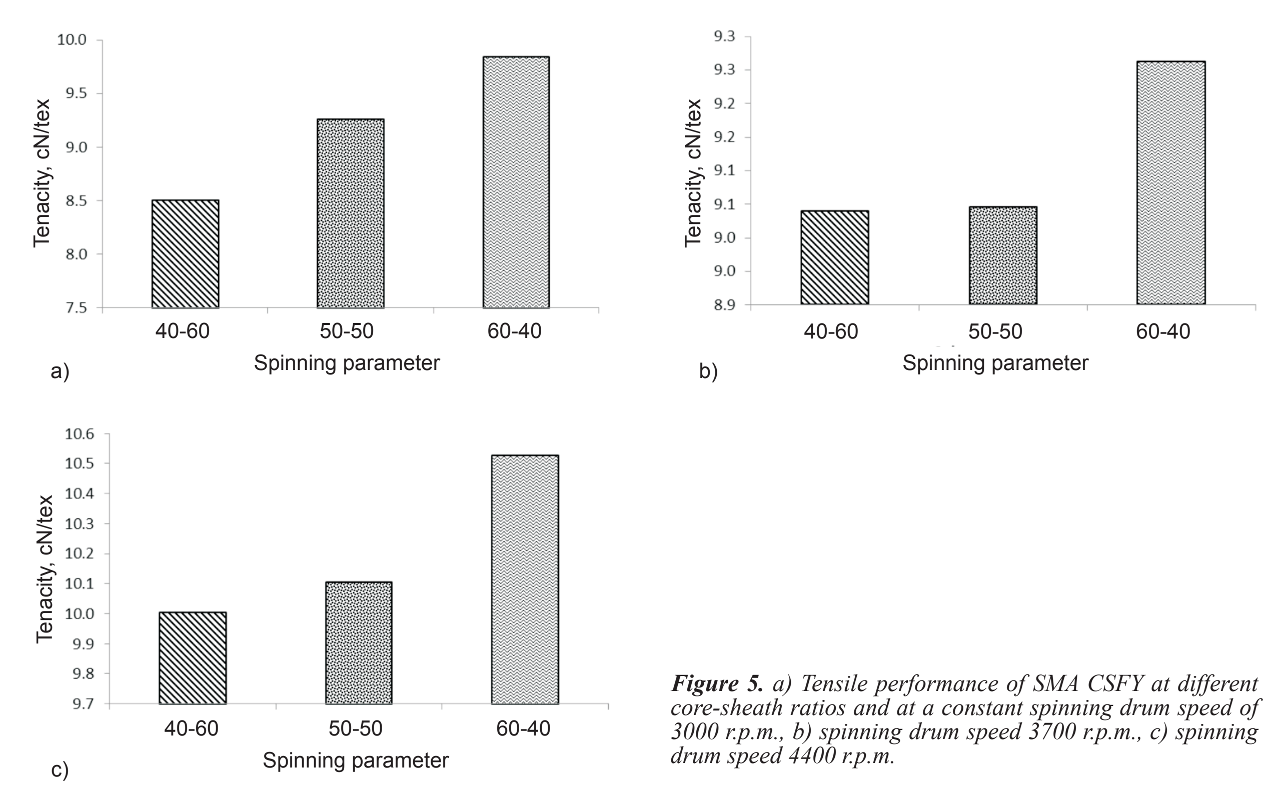

__Figure 5.__ a) Tensile performance of SMA CSFY at different core-sheath ratios and at a constant spinning drum speed of 3000 r.p.m., b) spinning drum speed 3700 r.p.m., c) spinning drum speed 4400 r.p.m.

for the yarn to start and stop activation was recorded. Five samples were tested for each process parameter. The behaviour of the yarn during actuation until completely deformed was also observed and recorded.

Results and discussion

SMA CSFY tensile strength

The results of the yarn tenacity are shown in ***Figures 5.a, 5.b*** and ***5.c***. It can be seen that the yarn at a constant spinning drum speed showed an increase in tensile strength regardless of the core ratios. A higher spinning drum speed increased the twist level of the yarn, thus the core components were probably faced with the great hold-ability of the sheath component. It can be said that as the core portion increases, the yarn tenacity would also increase. On the other hand, as the sheath component increases, the yarn becomes bulkier, thus having less hold-ability of the core component. Overall the strength of the SMA CSFY yarns was lower by about 50% in comparison with the SMA wire, which may be due to the movement of the core in the yarn, which could also have received a slight twist during production, leading to a reduction in the strength of the wire. Then the SMA CSFY's strength remains because the wire has still not broken inside the core. This remaining strength creates yarn with improved elongation at the peak (mm) of the resultant yarn. ***Figure 6*** shows the elongation at the peak of SMA CSFY in comparison with the SMA wire. The elongation at the peak value was similar to that of the wire.

SMA CSFY actuating performance

The SMA CSFY successfully actuated itself into an annealed shape (in this case, the wire was annealed in a spiral form) (see ***Figure 7***). The changes in the spinning drum speed were reflected by the actuating performance of SMA CSFY. As can be seen in ***Figure 8***, as the spinning drum speed increased, the time of actuation decreased, which may be due to the difference in the twist imparted to the yarn, the stiffness of the yarn produced, the hold-ability between the sheath and core material, and the temperature obtained for actuating. The increase in the spinning drum speed will increase the twist given to the yarn. Yarn with a high value of twist will become stiffer in comparison with yarn with less twist, which is caused by fibres holding tightly to each other. Hence when SMA wire is placed at the core component, the yarn will be given a better hold-ability by the fibres themselves, making the wire very close to the fibres. The temperature will be transferred more quickly to the wire inside the yarn as there is no gap between them. Any gap that existed between the wire and fibres will probably an increase in the time for the wire to achieve the temperature. ***Figures 9.a*** and ***9.b*** (see page 72) show a cross-section of SMA CSFY at a 3000 and 4400 r.p.m. spinning drum speed at a 50-50 core-sheath ratio (images were taken using Field Emission Scanning Electron Microscopy).

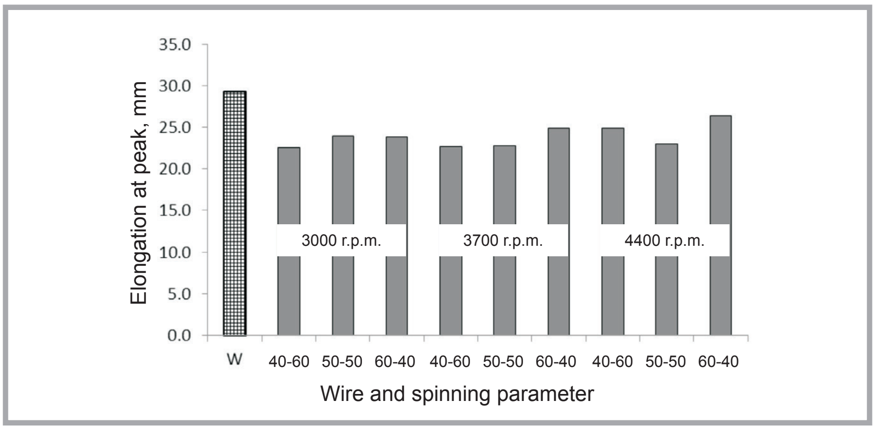

Figure 6. *Elongation at peak performance of SMA CSFY vs wire.*

Conclusions

SMA CSFY was spun using the DREF 3000 spinning system by varying the core-sheath ratios and spinning drum speeds. The SMA CSFY did not need to be treated using a high temperature heat treatment process to determine a pre-programmed shape because it was annealed before the spinning process took place. Additional 100% cotton spun yarn was suitable to assist in inserting the wire and core sliver together into the spinning zone since it was able to support the slippery surface of the wire during the transporting action of the core sliver. The vacuum condition in the oven for the actuating performance test tended to prevent other disturbances from the surroundings like wind and uncontrolled temperature. The tensile strength as well as the actuating performance of the yarns

Figure 7. *SMA CSFY actuated into a spiral shape.*

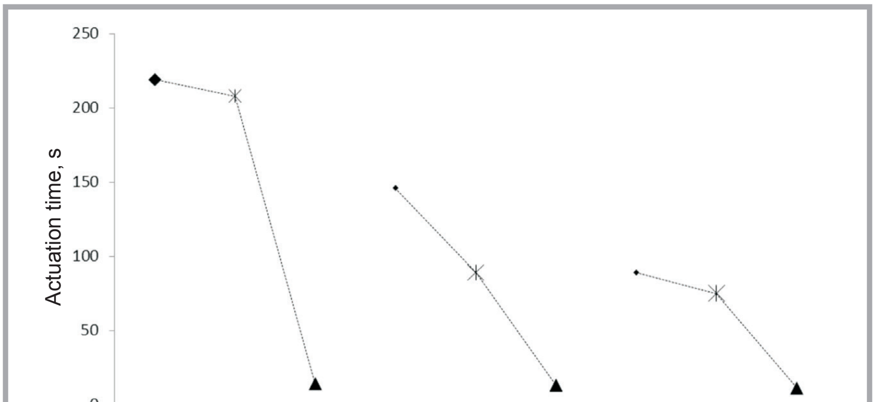

Figure 8. *Actuating performance at different spinning drum speeds and core-sheath ratios.*

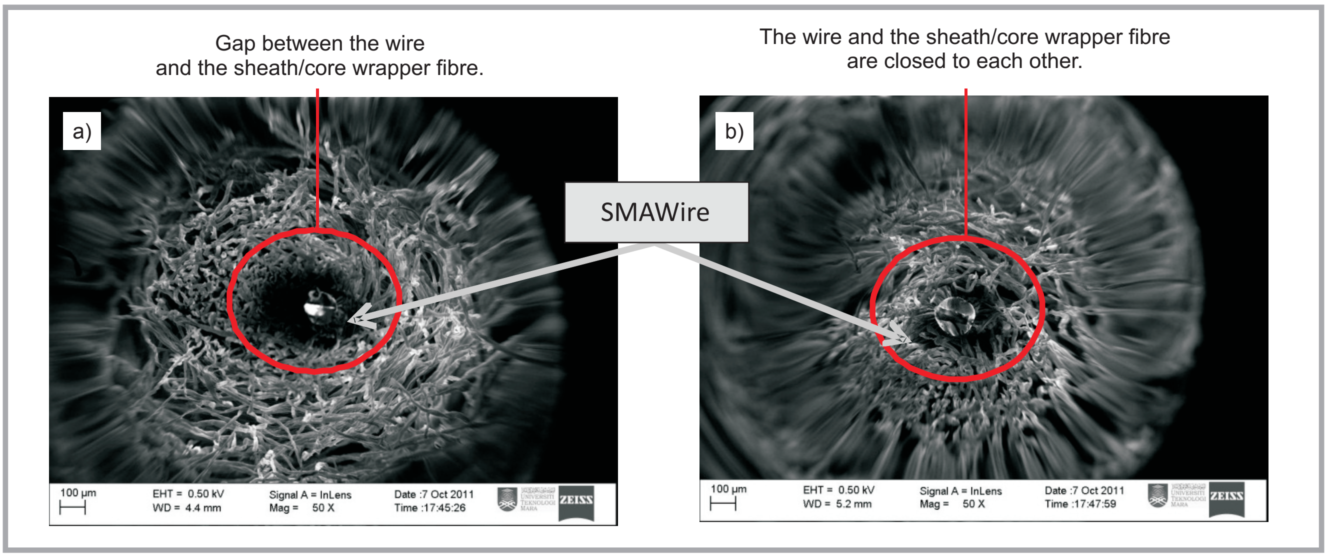

Figure 9. *a) SMA CSFY cross-section with 3000 r.p.m. and b) 4400 r.p.m. spinning drum speed (both spun with 50-50 core-sheath ratio).*

were established, and it can be concluded that the SMA CSFY produced with the highest spinning drum speed and 60-40 core-sheath ratio gave the highest tensile strength as well as actuating performance. The performance of this functional yarn in relation to other properties such as electrical properties still needs further investigation.

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