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Analysis and Evaluation of Shape Memory Alloy Wires Behaviour in Weft-Knitted Fabrics

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Abstract: It is widely acknowledged within the textile engineering community that Shape Memory Alloys (SMA), exhibit great potential for several applications. This paper presents the research undertaken at the University of Minho aiming to study the behaviour of weft-knitted fabrics produced with SMA nitinol® wires. SMA nitinol® wires of type B (which shows shape memory effect at body temperature) of 50, 127 and 210 µm diameters have been used to produce weft-knitted fabrics with different loop types, e.g. stitch, tuck and miss. The influence of the loop type on the performance of the weft-knitted fabric, in terms of energy absorption, has been analyzed. Tensile tests were carried out according to ISO1462 standard, using a H100KS Hounsfield universal testing instrument. The results aim to help future applications of SMA in the development of new textile materials.

1. Introduction

Ultimately, fibers, yarns, fabrics and other fibrous structures with added-value features have been successfully developed for specific applications as technical and/or high performance end uses. An excellent overview of smart technologies for clothing design and engineering was provided by Tang and Stylios[1]. Technical textiles have been promoted as alternative materials for an unlimited range of applications including medical, automotive, aerospace, civil and mechanical engineering, among others. Especially on clothing sector, high performance materials have attracted much interest for design and for the sport and protective clothing[1].

According to Tao[2], shape memory materials have been considered as a ultra-smart material, because they have the ability to sense stimuli and react according to the programmed way, by moving the internal molecular structure, leading the material for a pre-programmed shape. These physic factors stimulate the Shape Memory Effect (SME), making them to reach and transform as a specific shape, position, force or another pre-programmed characteristic[3]. Wherefore, when the stimulus is applied on a SMM, this must return to its memorized shape without deformations. However, the SME should be only performed if the stimuli achieve the glass transition temperature of SMM[4]. Shape memory materials (SMMs) can rapidly change their shapes from a temporary shape to their original (or permanent) shapes under appropriate stimulus such as temperature, light, electric field, magnetic field, or others[5].

Shape memory alloy wires are widely used for permanent works in various applications such as on stents[6], eyeglass frames, coffee pot thermostats, electrical connectors, heat pipes, clamps, and sculptures, medical apparatus, textiles applications, among others.

SMMs show the unique properties of shape recovery (SME) and pseudo-elasticity, as well as high fatigue strength and damping effect[7]. SMMs have attracted scientific interest and have been used in several industrial sectors, especially due to its thermo-mechanical properties such as shape memory effect and pseudo elasticity, which are associated as occur the martensilic transformation phase (MPT)[8].

The SMAs have been used in textiles, due to their functional and aesthetical application. The processability of SMA in textile field is dependent upon a range of factors to be conducted in a positive manner, among which stands out the flexibility of the wire (required to being knitted) [9].

The SMA can be woven and knitted, both in their original wire form, and as bi-component yarns. Good aesthetic shape memory effects have been produced using SMAs in the clothing industry, with interesting "lively" effects on the garment. However, the incorporation of an excessive amount of alloy wires in the textile structure may lead to a detrimental effect on the handle and touch of the fabric[10,11]. Challenges in the manufacturing and making-up processes, mostly caused by the lack of extensibility of the alloy during weaving or knitting, also need due consideration.

Under certain situations, to improve the processability of the material, the SMA wire may be combined with others natural fiber yarns, once over the SMA programming process, 550°C, those yarns may disappear, allowing the SMA to get a three-dimensional structure[12].

2. Materials and Experimental Methods

2.1 Materials

Three different nitinol® wire diameters have been used to produce three types of loops, generating nine different samples. The samples were produced on a flat knitting machine, with 8 needle/inch, based on a single jersey structure. Nitinol® wires with three different diameters, i.e, 50µm, 127µm and 210µm, type B (which shows SME at body temperature), were used to produce weft-knitted fabrics with three different loop types: stitch, tuck and miss. The structural parameters of the samples are listed in Table 1 and the physical and mechanical properties of SMA Nitinol® type B, are refereed at Metalle[13].

Table 1. Structural parameters of the samples

Parameter	Miss loop			Stitch loop			Tuck loop		
Wire diameter (µm)	50	127	210	50	127	210	50	127	210
Loop Length (mm)	3,7	4,9	4,2	4,9	6,7	6,1	5,4	7,2	6,9

A 70Tex acrylic yarn was used as a basis for the formation of loops with the nitinol® wires in the samples. The stitch loop structure (single jersey), Fig.1(a), was made using stitch loop on the basis structure and for the NiTi wire course. The knitted structure with tuck loops, Fig.1(b), were produced by alternating stitch loop with tuck loop in adjacent needles in the same course. The knitted structure with miss loops, Fig.1(c), were produced by alternating stitch loop with miss loop in adjacent needles in the same course.

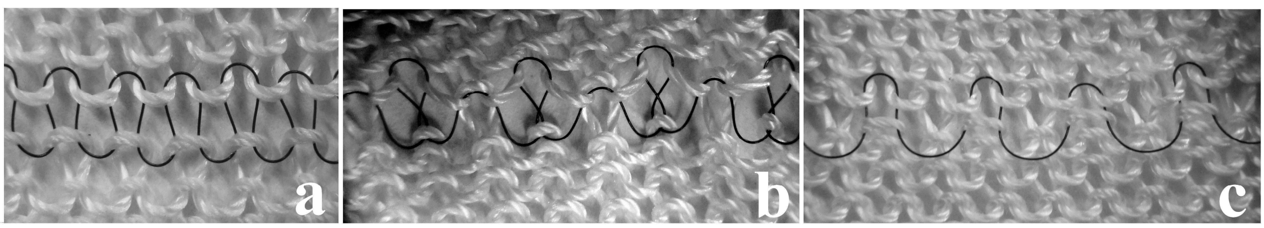

Fig. 1. Knitted structures showing stitch loop (a), tuck loop (b) and miss loop (c).

After the fabric production, the NiTi course had been removed from each sample, as shown in Fig. 2.

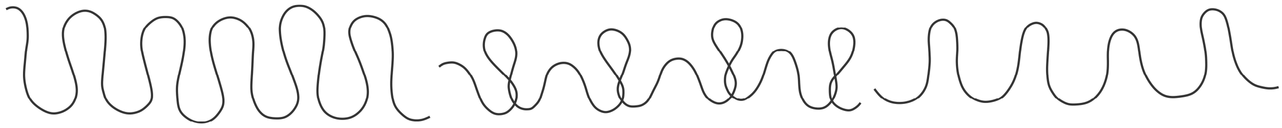

Fig. 2. Knitted courses produced with NiTi wires

The NiTi course samples were then placed into an oven with a temperature of 550°C, during 30 minutes[14], in order to memorize the shape of the wires, according to the deformed loops.

2.2 Experimental methods

Samples of NiTi knitted courses were used to analyse the deformation force energy (Fig. 3). The Tensile tests were carried out according to ISO1462, using a H100KS Hounsfield Universal Testing Instrument, using an initial gauge length of 95mm and crosshead speed of 10mm/min. Three tests were carried out for each sample, to calculate the influence of the loop type on the performance of the weft-knitted fabrics, in terms of energy absorption.

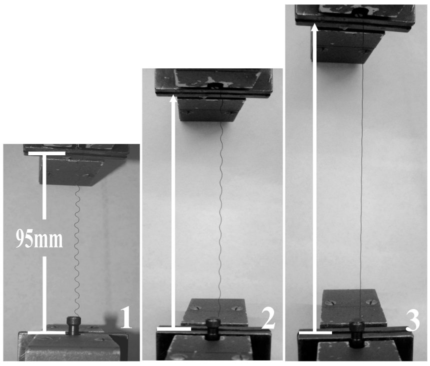

Fig. 3. Testing method: initial position (1), medium deformation (2) and straight (3)

The values were generated for each experiment and have been treated using the software OriginPro®8.

3. Results and Comments

3.1 Influence of the wire diameter in different types of loop

The typical stress-strain curves for the samples with the same loop type and varying the diameter of the wires are shown in Figs. 4, 5 and 6. Fig. 4 shows the behaviour of the NiTi® wires deformed in stitch loop, and the Fig. 6 and 7 are showing the results for miss and tuck loops, respectively.

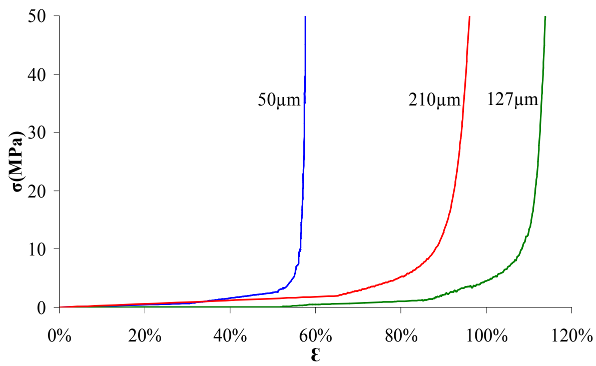

Fig. 4. Stress-strain curves for different NiTi wires in stitch loop structure

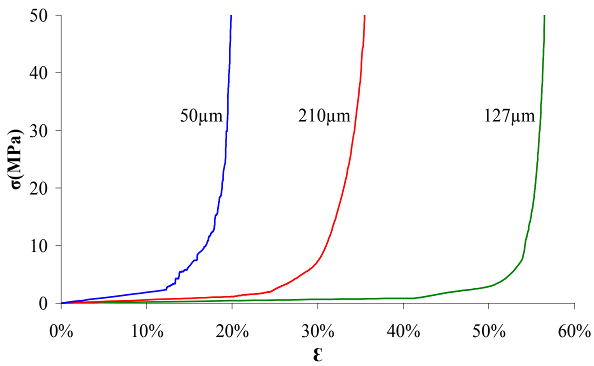

Fig. 5. Stress-strain curves for different NiTi wires in miss loop structure

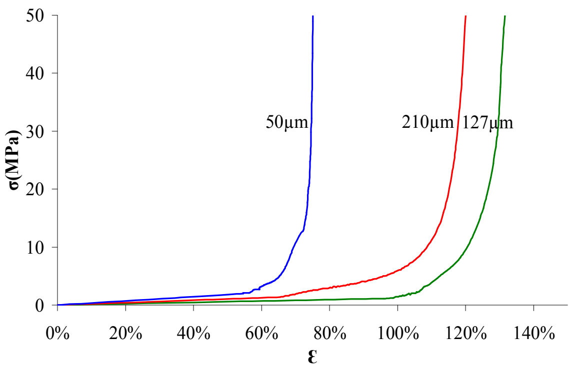

Fig. 6. Stress-strain curves for different NiTi wires in tuck loop structure

The load extension curves are showing a typical tensile behaviour of the wires in the form of the different loops studied. This behaviour might be split in two different parts: part 1 corresponds to the structural deformation of the loops and it is characterized by low stiffness once very low loads lead to high deformations; part 2 corresponds to the material deformation of the wire and is undertaken when this is in its the straight form after loop deformation.

As can be seen, the diameter of the NiTi® wire greatly influences the behaviour of the loops in their first part of the deformation as the deformation up to the jamming point is varying according to this factor.

3.2 Influence of the loop type for different diameters

The typical stress-strain curves for the samples using the same NiTi wire and varying the loop type are shown in Figs. 7, 8 and 9. The Fig. 7 shows the behaviour for stitch, miss and tuck loops structures studied.

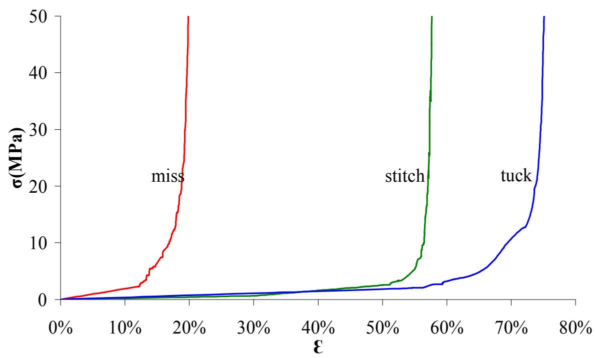

Fig. 7. Stress-strain curves for 50μm NiTi wire for different type of loop structure

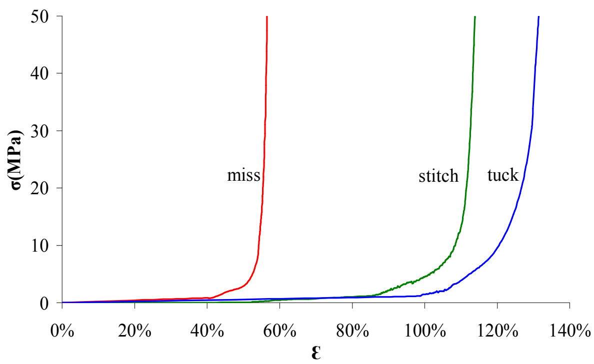

Fig. 8. Stress-strain curves for 127μm NiTi wire for different type of loop structure

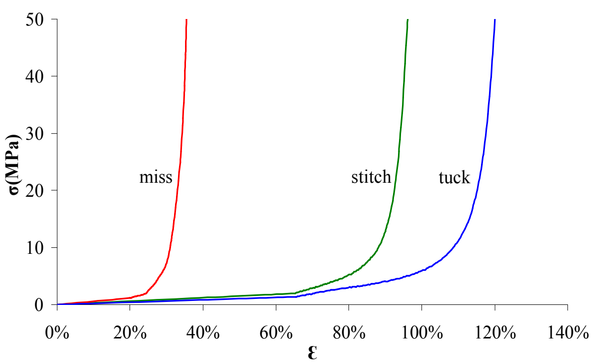

Fig. 9. Stress-strain curves for 210μm NiTi wire for different type of loop structure

As expected, the results showed that the loop type, greatly influences the tensile behaviour of the NiTi wire and this is dependent on the alignment of the wire to the axial force being applied. In this way, the initial part of the curve for all NiTi® diameter wires is increasing from miss to tuck loops.

3.3 Energy absorption analysis and comments

The energy absorption for the different loop types was calculated using the software OriginPro® 8. The energy absorption was calculated using the mechanical deformation data. For this calculation the area corresponding to the initial part of the curves to the point where the loop deformation stops and begins the elastic zone of the material, has been considered. The results are shown in Figs. 10, 11 and 12, respectively and the resume is shown in Table 2.

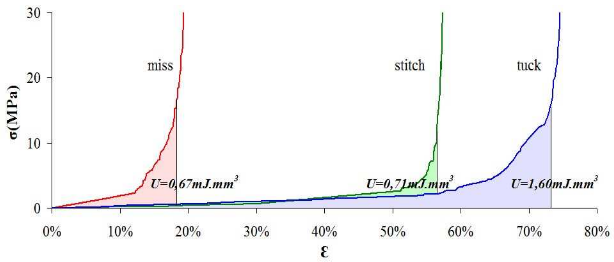

Fig. 10. Deformation energy of 50µm NiTi wire for different type of loop structure

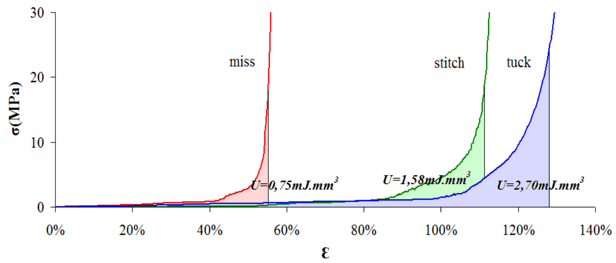

Fig. 11. Deformation energy of 127µm NiTi wire for different type of loop structure

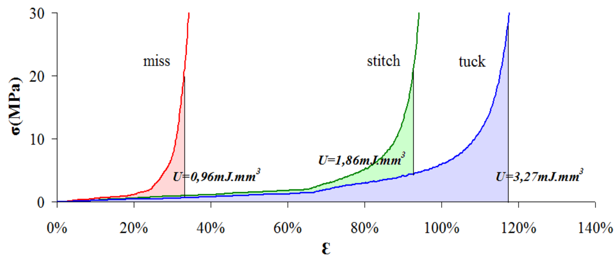

Fig. 12. Deformation energy of 210µm NiTi wire for different type of loop structure

Table 2. Energy absorption for different loop types

Energy		NiTi wire diameter		
		50µm	127µm	210µm
Loop type	Miss	0,67mJ.mm^3	0,75mJ.mm^3	0,96mJ.mm^3
	Stitch	0,71mJ.mm^3	1,58mJ.mm^3	1,86mJ.mm^3
	Tuck	1,60mJ.mm^3	2,70mJ.mm^3	3,27mJ.mm^3

4. Conclusions

Different types of weft-knitted loops using NiTi wires have been. Several conclusions could be taken considering the processability of the NiTi wires:

- the 50µm wire showed to be too thin to be knitted in the flat knitted machine 8 gauge;
- the 50µm wire does not represent great percentage of SMA in the knitted structure, which can avoid its smart effect;
- the 210µm NiTi wire shown to be hard to process on the knitting machine due to its high stiffness. In Table 2, are shown the resume for the energy absorption for different loop types.

Finally, for the same NiTi wire diameter, tuck loop presents the highest energy absorption capacity. More over, larger energy absorption capacity has been obtained for higher NiTi wire diameters. The results obtained may be a good contribution to design weft-knitted structures with shape memory ability.

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