Functional textiles driven by transforming NiTi wires

Weaving textiles from nickel-titanium (NiTi) wires offers a way to give garments a ‘shape memory’ where they can return to their original shape after being deformed by applying heat. Dr Ludek Heller and Dr Peter Sittner, at the Institute of Physics of the Czech Academy of Sciences, have found new ways to make and process wires to take advantage of the numerous, exciting applications of their NiTi wire technology, including in the manufacture of protective clothing for firefighters and astronauts.

Imagine a dress that, no matter how much you crumpled it up or wrinkled it, could pop back to its original shape, just with a little heat. Imagine clothing that could move and morph designs, just by changing the temperature of the environment. All of this can now be achieved in the era of ‘smart’ or ‘technical’ textiles, where new technologies are being combined with traditional textile manufacturing to create high performance materials with a whole variety of exciting applications.

It is not just high fashion and design that has been making use of the rapid development of technical textiles. Sportswear manufacturers are very interested in technical textiles that help better regulate body heat, or offer better protection in extreme weather conditions. These applications are not just limited to clothing either – technical textiles can now be found in bandages that have enhanced antibacterial properties to reduce the probability of post-operative infections.

Among these, one of the most exciting developments is the use of shape memory alloys in technical textiles. These are materials that can be set into a shape and, no matter how they are distorted, they will return to their original shape on heating. This is how ‘animated’ dresses can be created that seem to move of their own free will.

Dr Ludek Heller and Dr Peter Sittner, at the Fyzikální ústav AV ČR, are experts in this highly interdisciplinary area. Their research is about finding new ways to combine nickel-titanium wires with traditional textiles to achieve many of the proposed novel applications. Dr Sittner describes their role as being, “physicists – metallurgists – mechanical engineers, that, coupled with textile manufacturers, make hybrid metallic textiles”.

PROPERTIES OF NiTi

Why is NiTi the alloy of choice for making the wires that are combined with traditional yarns? NiTi (sometimes called NiTiNOL, an acronym derived from its composition and place of discovery – Naval Ordnance Laboratory) is the most commercially successful shape memory alloy. NiTi wires and thin filaments have functional and structural properties outperforming other shape memory alloys.

NiTi is relatively easy to process into wires that range in diameter from a few to tens of microns thick – roughly the thickness of a human hair. They can be combined with traditional yarns made from cotton or wool to make a variety of different fabric types. The stretchability of the NiTi wires (due to their superelastic functional property) is fairly similar to the blended yarns so the overall fabric is suitable for use in items like clothing.

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Figure 1: High energy synchrotron x-ray diffraction helps to detect accumulation of residual stress and residual martensite upon superelastic cycling of thin NiTi filaments due to concurrent martensitic transformation and plastic deformation by slip.

Figure 2: Reversible straightening of a single knit loop made from a 150 μm NiTi wire subjected to tensile loading. The straightening is accommodated via a solid state transformation of the initial austenite phase. This deformation mechanism was tracked using microdiffraction tomography revealing the spatial distribution of martensite and its phase induced by bending dominated loading.

**SHAPE SETTING OF NiTi TEXTILES**

Imagine textiles that look like a normal fabric but have shape memory properties. For this, textile processing combining both the NiTi wire and common yarns has been successfully tested. For instance, when the textile is constrained in a desired shape allows researchers not only to induce shape memory properties in NiTi but also to shape-set NiTi wires creating the shape of the entire fabric (see main image). This process of the constrained heat treatment of NiTi wires is called shape setting. A unique NiTi textile architecture of NiTi textiles is created partially by weaving (knitting) and partially by the shape setting process. In such a way the shape and the macroscopic shape of the 2D textile can be set as well. The key issue when shape setting hybrid NiTi textiles is to heat treat the NiTi wires while protecting the surrounding heat-sensitive yarn. Shape setting at moderate temperatures is the only way to achieve that. Dr Heller and Dr Sittner’s research team has been exploring how to shape-set NiTi wires at temperatures as low as 250°C, employing the reverse martensitic transformation driven by the supplied heat.

Shape-set NiTi wires embedded in textiles have wave geometry due to their interlacing with the textile patterns. This wavy geometry allows for no lock in or for a fine NiTi wire, this idea comes naturally. The fine NiTi wires possess the magic shape memory properties and are stronger than bars or thick wires. So why not combine multiple thin wires using textile processing technologies to make superelastic cables or textiles with memory of shape or roughness? Indeed, by setting a densely wrinkled shape on a flat textile, it will remember it as long as it is not stretched. From another perspective, textile internal architecture can be modified by shape setting. A variety of textile patterns NiTi wires are loaded in bending, giving the textile compliant mechanical characteristics that are very different from woven structures with two perpendicular sets of nearly straight wires that are straight and shape memory properties and the ability to change the stiffness, recover strains, and exhibit tensile stresses hundreds of MPa by changing temperature by a few tens of degrees Celsius. As a result, the NiTi wires can be easily shape set into any tortuous shape.

**What Inspired the idea of using NiTi wires in textile applications?**

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**What are the properties that make NiTi wires so special?**

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This end, synchrotron X-ray microdiffraction was used to identify martensitically transformed zones within a wavy 100 micron NiTi wire while being stretched, mimicking the NiTi wire loading in weft knitted NiTi textiles (Figure 2).

NI Ti TEXTILES
Embedding NiTi wires into textiles enables the engineering of a complex 3D structure thanks to the shape setting. Such NiTi structures can repeatedly undergo large strains thanks to both NiTi atoms shuffling back and forth, and wavy geometry of NiTi wires allowing for large deflections. These NiTi structures may be extremely compliant and soft at one temperature while becoming stiff and hard upon being heated by just a few degrees. The key for the successful design of NiTi textiles is to interface NiTi wires into smart patterns. A collaborating textile engineer K. Janouchova, together with Dr Heller and Dr Sittner, has been working on designing lightweight, hollow 3D textiles using a unique weft knitting pattern. This forms a temperature-responsive spacer fabric that can triple its profile thickness when the temperature is changed by 30°C or lift up to 2000x its own weight. One application for this smart spacer fabric is as thermally protective cloth (Figure 3).

FUTURE CHALLENGES
The research group has already been awarded several patents for their work, including one for a low-profile stent graft (used to repair damaged blood vessels). The extreme thinness of the stent graft means the diameter of the delivery system catheter can be decreased. The graft is made from a unique woven textile incorporating 30 microns of NiTi wires combined with medical grade yarns that are low temperature shape-set into a tubular textile. Another patent is for developing a Velcro-like fastener that is made from an array of NiTi ‘hooks’ which open and close silently. This fastener is also immune to dirt and oil that can clog conventional Velcro fasteners stopping them from working.

At present, NiTi use has mostly been restricted to medical, aerospace and automotive applications due to the costs associated with manufacturing. Shape-settable hybrid NiTi textiles offer a wide range of new applications, for example in medical devices or wearable electronics. Key technologies have already been developed for textiles made from superelastic filaments. The work of Dr Heller and Dr Sittner represents a major breakthrough in NiTi textile production from drawn filaments with subsequent heat treatment for simultaneous adjustment of the functionality, textile architecture and shape. Incorporating NiTi wires into textiles on an industrial scale, however, still poses challenges due to the additional machinery wear and friction from working with the metallic alloys during textile production. However, given the exciting applications, NiTi textiles will become ever more attractive as time goes on.