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A NEW WIDE HYSTERESIS NiTi BASED SHAPE MEMORY ALLOY AND ITS APPLICATIONS

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A NiTi based shape memory alloy has recently been developed which has a very wide hysteresis of over 150°C. By locating ambient temperature within the loop, fastening or connecting elements can be stored in the deformed (martensitic) condition, installed by heating, yet remain austenitic to well below room temperature. Some commercial applications of this new alloy are described.

I. Introduction

One of the first major commercial uses of shape memory alloys was pioneered by Raychem Corporation in 1969. The application was as couplings for aircraft hydraulic tubing in the Grumman Aircraft Corporation F-14 fighter. Today, nearly half a million leak-free installations later, the product continues to be used. The NiTi-based couplings are made from an alloy with a transformation temperature substantially below the lowest anticipated service temperature of -65°C. Machining of the couplings is done at room temperature in the austenitic phase; they are subsequently cooled in liquid nitrogen and then expanded in the martensitic condition.

Expanded couplings are shipped and stored in liquid nitrogen. Installation requires inserting the tubes or pipes into the coupling and allowing them to warm to room temperature. The coupling tries to recover to its original dimension and bites down onto the tubes forming a highly reliable joint. Throughout its service life, the coupling then remains in the high temperature austenitic phase where it maintains its strength.

The requirements for shipping and service temperature ranges are illustrated in Figure 1. During shipping and storage the expanded coupling should remain below A_s so that no premature recovery occurs. However, if the operating temperature enters a range where transformation to martensite can occur, then the coupling will relax, causing a potential leakage. Thus the service temperature should exceed M_s. Since the pipe is being elastically compressed by the coupling, then the effect of this force on M_s should be considered. It is known that M_s increases with increasing stress, and so the zero-load M_s should be well below the lowest anticipated operating temperature in order to avoid these problems.

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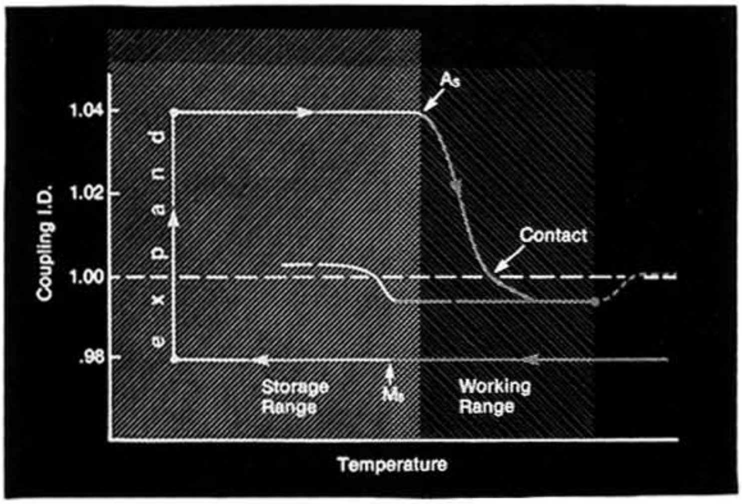


Figure 1: Schematic illustration of coupling diameter changes on heating and subsequently cooling.

An interesting effect which can occur on cooling below M_s, is that the coupling in fact opens up beyond the pipe size and becomes loose. This is probably a result of a two-way type of effect. On cooling in the presence of this elastic force, some variants of martensite are preferentially nucleated. When the stress goes to zero (the coupling and pipe only just touch) continued growth of these variants can cause a further small shape change and the coupling becomes loose.

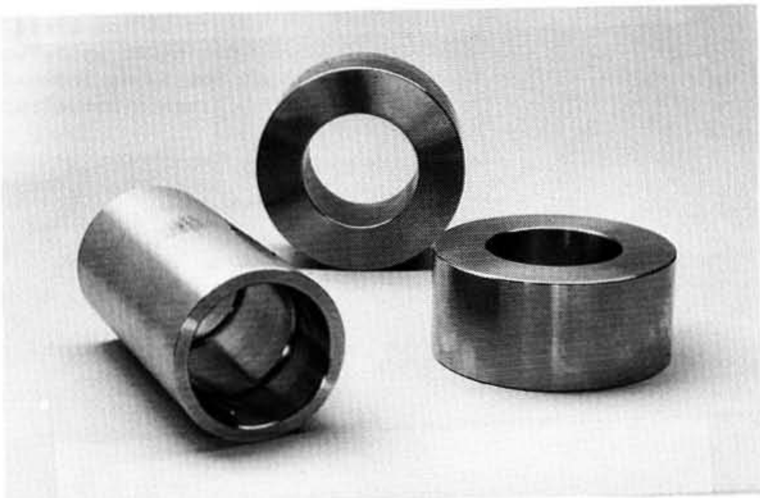
The hysteresis width of the martensitic transformation in conventional NiTi based alloys is typically in the range of 30 to 50°C, [1] which means that these limitations can only be met with both A_s and M_s substantially below ambient temperature. Consequently the need for liquid nitrogen shipping has been a factor in limiting the usage of these couplings.

In a recent development [2] an improved NiTi based alloy has been found, which has a much wider hysteresis than any previously reported shape memory alloy in this system. The hysteresis loop is wide enough to position ambient temperature within it, and have adequate ranges for shipping and service. Components can now be shipped and stored at ambient temperature in the martensitic condition, then installed by heating using any appropriate heating technique. Once installed, the alloy remains functional down to -65°C or, in other words, the zero stress hysteresis is greater than 150°C. Premature recovery does not occur unless the coupling is exposed to temperatures in excess of 55°C. In this paper, some applications of this new material will be described.

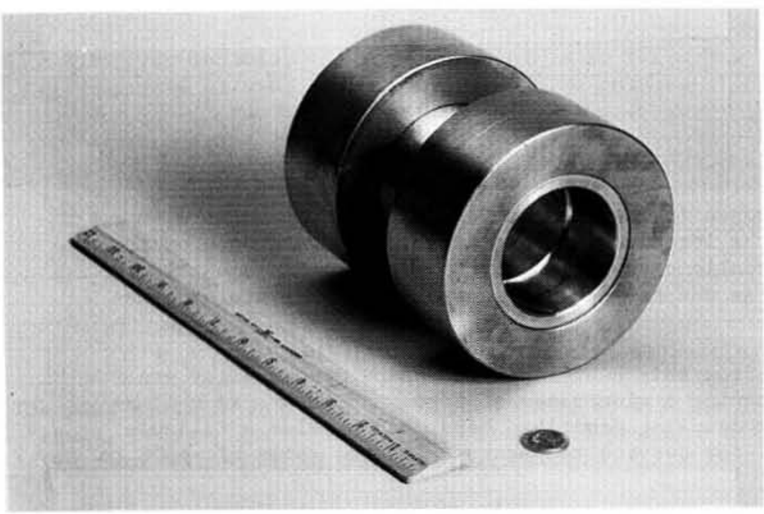
II. Subsea Coupling

Joining or repairing pipes underwater is a difficult process and one where the ease of installation of shape memory alloy couplings make them very attractive, providing the subsea industry with a simple and cost effective solution. Using conventional alloys requires the use of a liquid nitrogen (LN) containing pressure vessel [3] and LN storage on an offshore platform may provide some problems.

Figure 2: Subsea Coupling



a) Shape memory alloy rings and liner.



b) Expanded and assembled.

Figure 2: Subsea Coupling (continued)

c) Installed and burst on 2.375" pipe.

The new heat-to-shrink technology provides the advantages of a shape memory alloy solution but eliminates the logistics problem of LN shipping and storage. Figure 2 shows an example of such a coupling for 2.375" (60.325mm) diameter thick walled pipe, using two rings in the new shape memory alloy material. On heating, the rings crush the liner, driving teeth machined on its inner diameter into the pipe, thereby creating an effective metal to metal seal. A critical part of the design is the configuration of these teeth, which have to bite through possible oxide or scale, coin out scratches and other potential leak paths, yet provide enough shear strength that the pipes cannot be pulled out with low tensile forces.

The liner is chosen from a material chemically compatible with pipe material and the intended fluid inside. Tests were done on these assemblies by internally pressurizing with hydraulic fluid until failure occurred. As can be seen in Figure 2c, the failure mode was burst of the pipe.

Couplings made from this heat-to-shrink shape memory alloy are being applied to joining a wide range of tubes and pipes, as well as the specific subsea coupling described here, and provide a reliable metal to metal seal for service temperatures in the range of -65°C to over +300°C.

III. Braid Termination Systems

A heat-to-shrink ring is used to permanently attach cable EMI shielding braid to the backshell of a connector, as in Figure 4. The rings can be recovered in less than 10 seconds with a resistance heater; thermochromic paint indicators supplied on the ring change colour when the proper installation temperature is reached. The heat recovered rings provide a joint with a DC resistance of less than 1 milli-ohm and a tensile strength in excess of 200 lbs. High frequency shielding is optimum due to the 360 degree peripheral contact between the braid and adapter. The joint is unaffected by the ambient temperature range required of the connector (-65°C to +150°C) and by mechanical shock and vibration, and provides an operator insensitive installation compared with soldering and threaded fasteners.

(a) (b)

Figure 3: A backshell connector using a shape memory alloy ring.

a) Shape memory alloy ring.
b) During installation with an electrical heating tool.

The ring shown in Figure 3 was manufactured by welding drawn wire. This results in very little material wastage and provides a less expensive ring than would be possible machining.

IV. Conclusion

The development of this new nickel-titanium based heat-to-shrink alloy opens up completely new directions for shape memory application. Eliminating the need for liquid nitrogen will allow use of shape memory fasteners, connectors and couplings in markets previously difficult to penetrate.

References

[1] K. N. Melton and O. Mercier: Acta Met., 29(1981), 393.
[2] Patent Pending, Raychem Corporation, Menlo Park, California.
[3] A. Bushell, J. Harrison and L. Hill: Proceedings of the International Conference on Martensitic Transformations, ICOMAT 1979, p. 699.