Investigation on the connecting strength of Fe-Mn-Si-C shape memory alloy pipe coupling

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Since the shape memory effect in Fe-Mn-Si alloy was first reported by Sato et al. [1], many works have been focused on this kind of shape memory alloy due to their low cost and excellent workability [2, 3]. However, the shape memory effect in Fe-Mn-Si based alloy is incomplete and the recoverable strain is quite low compared with Ni-Ti and Cu based shape memory alloy. Many efforts have been made to improve the shape memory effect through thermomechanical treatment (training) and alloying [4–7]. Fe-Mn-Si based alloys are expected to be used as pipe couplings. The most important property of pipe coupling is the connecting strength, which determine the pressure and mechanical load the pipe coupling can bear. However, there is little report on the connecting strength of pipe coupling made of Fe-Mn-Si based shape memory alloy.

Our previous work [6] shows that the carbon addition to Fe-Mn-Si alloy can improve the shape memory effect and increase the recovery stress obviously. The increase of recovery stress will be beneficial to the connecting strength of pipe coupling. At present study, pipe couplings were fabricated by a Fe-Mn-Si-C shape memory alloy. The effects of prestrain, connecting length and the wall thickness of coupling on the connecting strength of pipe coupling are investigated.

The alloy of Fe-18.1Mn-6.3Si-0.32C (wt.%) used in this study was prepared by vacuum induction furnace. The ingot was forged after being homogenized at 1373 K for 12 h. The semifinished pipe couplings were cut from the ingot and then were machined into pipe couplings with varied internal diameter and wall thickness. The pipe couplings were heated to the 973 K for 10 min, followed by a water quench, which is an effective way of improving the shape memory effect [8]. In order to guarantee homogeneous deformation along the direction of the radius, the pipe couplings were expanded four times by different taper with small conical degree. The prestrain ε_p was estimated according to$\varepsilon_p = (d_1 - d_0)/d_0$, where d_0 and d_1 are respectively the internal diameter of the pipe couplings before and after the coupling is expanded. The internal diameter of the pipe coupling before expansion was different and then was expanded to 10.00 mm which equals to the external diameter of connected pipe. The pipes were fabricated by a quenched and tempered AISI1045 steel, with hardness of HV286. After the pipe couplings were expanded, two pipes were inserted to the pipe coupling and then were heated to temperature of 573 K for 10 min. After that the two pipes were connected by the pipe coupling. This process is illustrated in Fig. 1.

Tensile test of the connected pipes was carried out using an Instron machine. The connected strength is given by Equation 1 [9].

$$\sigma_c = F_p/\pi\mu dl \tag{1}$$

where F_p is the tensile load when one of the pipe was pull out of the pipe coupling, μ is friction coefficient of the steel (about 0.15), l is half length of the pipe coupling.

The effect of prestrain on the connecting strength of pipe couplings is shown in Fig. 2. The length of the pipe couplings is 40 mm, and the wall thickness of couplings is 2 mm. It can be seen that the connecting strength increase as prestrain increase, especially when the prestrain is larger than 1.5%. Without constrain, the prestrain under 3.5% can be recovered near completely [8]. In the case of pipe coupling, the shape recovery during heating is constrained. That will result in a pressure on the surface, which causes connecting strength under the tensile load. Therefore, the more the recoverable strain constrained, the higher pressure produced on the surface of the pipe, and the higher connecting strength caused.

Fig. 3 shows the effect of the connecting length (i.e. the length of pipe coupling) on the connecting strength of the pipe couplings. The wall thickness of the couplings is 2 mm, and the prestrain is 3.3%. It is found that the connecting strength increase as coupling length increase before 30 mm and then decrease as the connecting length increase further. The corresponding tensile load F_p is also illustrated in Fig. 3 too. It

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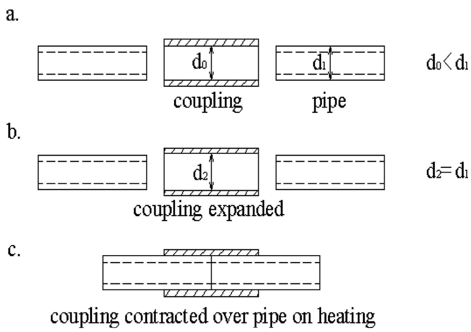

Figure 1 Connecting process of the pipe coupling (a) original pipe coupling and the pipe. (b) pipe coupling was expanded. (c) pipe coupling contracted over pipes on heating and the pipes were connected.

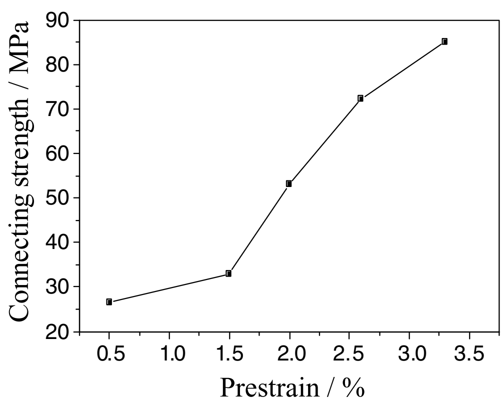

Figure 2 Effect of prestrain on the connecting strength of pipe couplings.

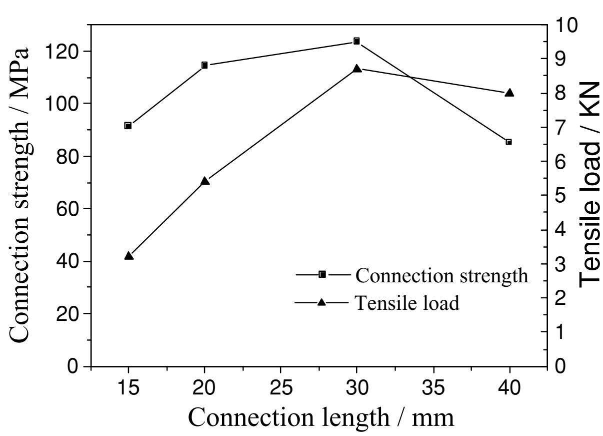

Figure 3 Effect of connecting length on the connecting strength and the corresponding tensile load.

can be seen that the tensile load F_p increase as connecting length increase obviously. When the connecting length is larger than 30 mm, the tensile load decreases slightly. The connecting strength is calculated by Equation 1. It is found that though the tensile load F_p increase as connecting length increase, the denominator (connecting length l) increase too. That result the relationship between connecting strength and connecting length is showed as Fig. 3.

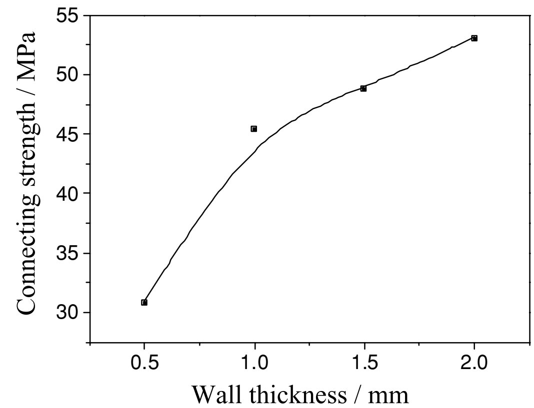

Figure 4 Effect of wall thickness on the connecting strength of coupling.

When the connecting length increases, the contacting area increases which cause the tensile load increase. However, there exist inhomogeneity on the surface of the pipe coupling and the pipe, such as shape error, dimension error, roughness and others. These inhomogeneities result in the pipe coupling and the pipe can not contact completely tightly. The true contact area is less than the nominal area. The inhomogeneities increase as the coupling length increase. The true contact area does not increase in step with coupling length increase. When the connecting length is larger than a specific value, the true contacting area may be reduced due to the surface inhomogeneity increase. Therefore the connecting strength increase as connecting length increase first and then decrease as the connecting length increase further.

The effect of coupling wall thickness on the connecting strength is illustrated in Fig. 4, showing that the connecting strength increases the coupling thickness increases. The connecting length is 40 mm, and the prestrain is 2%. When the coupling wall is thin, the stiffness and the strength of coupling itself is low, which result in the lower connecting strength of coupling. When the thickness of the coupling wall increases, the stiffness and the strength of the coupling increases, this causes the connecting strength increases.

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