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A Review Article on FeMnAlNi Shape Memory Alloy

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Abstract

Shape memory alloys (SMAs) are the materials which remember their original shape once after the deformation has occurred. In recent days, researchers started working on Fe-based shape memory alloys as NiTi shape memory alloys has few drawbacks. Fe-based shape memory alloys show better advantages over NiTi SMAs. FeMnAlNi SMA has advantage of wide range of operating temperature and low stress dependence. This review article provides information on work carried out on FeMnAlNi SMA which will help the researchers to carry further research work on the alloy for various applications.

Keywords: *Shape memory alloy, Superelasticity, FeMnAlNi alloy*

1.0 Introduction

Shape memory alloys (SMA's) are the materials which are going to remember their original shape once after the deformation has occurred i.e; capability to comeback to it's predetermined form after heating (1). Whenever the SMA is cold, it will be in martensite phase which is comparatively soft than high temperature phase i.e. Austenite (1). Shape memory alloys are also called by some other names such as smart materials, intelligent materials etc., due to their remembering properties.

The major properties of shape memory alloys are shape memory effect and super elasticity. The shape memory effect is due to increase in temperature during phase transformation and superelasticity is due to increase in stress during phase transformation (2). These materials are having two phases one is austenite phase and the other is martensite phase. SMA's go through phase transformation from austenite phase to martensite phase and vice versa (2). There are two types of SMA's which are one way shape memory alloys and two-way shape memory alloys. One way SMA's can be able to memorise the shape of material be it having shape during hot temperature whereas two way SMA's are able to memrise the shapes of material in which they are having the shape during both hot and cold temperatures (2).

2.0 History of SMA

In 1932 Chang and Read, first visualized the observation of shape memory transformation. From metallurgical observation and resistivity changes they observed the reversibility of transformation in AuCd alloy (3). Shape memory effect was first identified by Swedish physicist named Arne Olander in the year 1932 in AuCd alloy (1). The SME in NiTi alloy was identified in the year 1961 by U.S Naval ordnance laboratory (1). During 1970's more investigation has been done on Fe-based shape memory alloy.

3.0 Types of shape memory alloys

1. NiTi-based alloy

Nickel-Titanium alloy is commonly known as nitinol. In the mid of 1980's superelastic nitinol was identified by orthodontists for the application in the dental field (4). This alloy has some benefits due to their easy of manufacturing and machining methods, low cost and less danger in the health point of view (1). This alloy has some interesting properties like superelastic behaviour, causing of high recovery stresses, recoverable strains (5). This alloy has almost equal amount of nickel and titanium (6).

2. Iron-based alloy

Iron-based alloy are the one which came substitute to NiTi alloy for many applications because of its wide range of operating temperature, cost effective, damping capacity, superelasticity and other properties (7). Even with some advantages it has some drawbacks in shape recovery rate, and it has limited corrosion resistant and less shape memory effect (8).

3. Copper-based alloy

Copper based shape memory alloy is also one of the important types of shape memory alloy because of its large range of operating temperature and flexibility. It is also one of better replacement of NiTi alloy due to its less manufacturing cost (10). Despite of some advantages this copper-based alloy shows some sensitiveness to aging, transition hysteresis, phase stabilization which compresses the application of this alloy in various field (7).

In this latter time iron-based shape memory alloys have gaining more spaces in manufacturing field because of their high elastic stiffness, specific damping capacity, superelasticity, transformation strains and they are economical than any other NiTi or Cu based alloys.

4.0 Properties of FeMnAlNi SMA's

Depending upon the usage of the material the composition of the above alloy is varied as they exhibit different characteristics. Here the classic composition i.e; Fe-43.5%, Mn-34%, Al-15%, Ni-7.5% is used.

1 Shape memory effect

The change in phase occurs due change in its temperature, here the alloy changes from austenite phase to martensite phase upon coolling and it comes back to its austenite phase after heating.

Among many alloy the shape memory effect of NiTi shape memory alloy is better and is used for many of the application and for some minor application it can be replaced by Fe-based or Cu based alloys and due to less cost of Fe based alloy it is occupying more application field(11).

Aging treatment can improve shape recovery rate by 20-45% and further up to 51% after two step aging treatment. Cheap Fe based alloys are expected to be alternative to NiTi based alloys. When Ni is doped to Fe Mn Al alloy it strengthen the austenite matrix and block the dislocation during martensite transformation, this halt the plastic deformation and influence transformation to thermoelastic martensitic transformation and hence acquire good superelasticity (12,13).

2. Superelaticity

Phase change occur due to change in load condition, i.e; the austenite phase changes to martensite phase upon adding load, once after the load is removed it again comes back to its original austenite phase without change in temperature. NiTi alloy has more recoverable strain i.e; up to 8% until the FeMnAlNi has achieved large recoverable strain (up to 13.5%).

During martensitic transformation from ±-bcc to ³-fcc the superelasticity can be achieved which is infrequent in Fe based alloys (14).

Fe-based alloys have more importance because of their ease of processing and low cost of material but it has low recovery strains due to non-thermoelastic martensitic transformation that results in the large temperature and stresses but the major thing is the above classic composition i.e; $Fe_{43.5}Mn_{34}Al_{15}Ni_{7.5}$ shows a small temperature and low stresses and this composition alloy with [100] orientation it shows highest theoretical transformation strain under both in tension up to 26.5% and in compression up to 10.5%(15).

5.0 Crystallography of FeMnAlNi alloy

With the help of electron backscatter diffraction (EBSD) microstructure can be observed comprising A1-martensite and A2 austenite for different composition. Prediction carried based on phenomenological theory of martensitic crystallography (PTMC) is compared with experimental details. This will project the habit planes and the orientation relationship with the help of using PTC lab software. With more amount of iron, it shows very diffused EBSD design. If Mn amount is more then it reveals tetragonal distortion pattern of A1 martensite clearly. The results from both PTMC and EBSD almost well matches between them (16).

Thermomechanical processing

From this process the microscopic and macroscopic changes can be observed by little substitution of Al with Ni. To the classic composition the substitution of Al with Ni is done i.e; in classic composition Al is having up to 15% for that we add 1.5% more with substitute with nickel, this will leads to stabilized ±–bcc structure and if Ni is replaced in place of al that is in classic composition Nickel is having up to 7.5% but once after it gets replaced it is having up to 9% and that leads to more stabilized γ-fcc structure during this it will not reveal the grain boundaries.

Substitution of Al with Ni leads to decrease in ultimate stress in cold rolling and ultimate strain in hot rolling. However, the classic composition shows the better fibering structure than the other two composition (17,18).

7.0 Frequency effect

Past from 1938, SMA's are acting as fortunate functional materials till today. As the material is widely used its frequency effects should also need to be known, for that a small ingot of FeMnAlNi alloy is taken and that is encapsulated in a quartz tube under argon pressure. Here the material will be soultoinized at 1300^{o}C up to 1hr and it is quenched in water which is having 80^{o}C, afterwards it is aged for nearly up to 4 hr at 225^{o}C, which promotes B2 AlNippt. that inturn displays BCC austenite matrix and enhance thermoelastic martensitic transformation.

Due to low change in temperature during loading FeMnAlNi alloy shows rate insensitive stress-strain response whereas in NiTi alloy shows high rate sensitive because of its large change in temperature. FeMnAlNi alloy is one of best alloy to be used under damping application because of its zero-temperature dependence, rate insensitive behaviour and high specific damping capacity (19,20,21).

8.0 Promises and challenges of FeMnAlNi alloy

During the time when NiTi alloy is widely used the FeMnAlNi alloy with its large superelastic temperature occupied more place of NiTi alloy and acting as one of the most promising materials, the transformation stress is slightly dependent on temparature, during compression or the tensile load, that will be helpful in the application where fatigue resistance under dynamic loading is required. This alloy can be able to withstand high transformation stress level than many other alloys i.e; up to 500-600MPa. (22,23).

Still with all those benefit it has some defects in recoverability rate due to abnormal grain growth i.e; when the samplecross section is not completely covered by the grains. To avoid this problem a small amount of Titanium, Chrominium and lead is added which will strongly restrict the abnormal grain growth and to have more subgrain size (24).

9.0 Importance of FeMnAlNi alloy

In the presence of varieties of combination of alloy, the Fe-based alloy is very important, that too FeMnAlNi alloy is suitable for many of the application with its wide operating temperature, because it is having small vary in superelastic stress with large amount temperature rise (7). Whereas the other alloys will have large superelastic strees with small amount of temperature change which is not suitable for space or automobile application (14). With good superelasticity and specific damping capacity FeMnAlNi alloy is economical than NiTi or Cu based alloys (25).

10.0 Application of FeMnAlNi alloy

With its wide operating temperature this alloy has more advantage than any other alloys. In the application of space, we require a material which can withstand large change in temperature so for that this classic composition alloy is one of the best materials to be used. Used in the plane parts of engine turbine, compressor, wing, winglets, landing gears etc.

(26,27,28), also used in the field of automotive parts like air vents, headlights, safety straps etc., In the medical field for the purpose of stents (29,30,31), also in dental fields for braces of teeth, i.e used as biodegradable metals in the field of medicine (32,33) and also in the civil structure to withstand the vibration with high damping capacity(34).

11.0 Conclusion

Alloys are playing a huge role in enhancements of the industrial fields with their ability to suitable for different application. Some of the characteristics of FeMnAlNi alloy is studied in which it is having good superelasticity with large recoverable strain up to 13.5%(14). Shape recover rate can be increased by increasing the aging period also about the thermomechanical processing of the alloy. From frequency effect it ensures that this alloy is having zero temperature dependence and high damping capacity (19). Ability to withstand the transformation stress level up to 500-600MPa (22). Even with all this more work should be done on low recoverability rate due to abnormal grain growth. Usage of FeMnAlNi is increasing day by day due it's more advantageous characteristics than the NiTi or Cu based alloys.

12.0 References

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