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Research Article

INVESTIGATION OF Ni-Mn BASED SHAPE MEMORY ALLOY VARIATIONS TRANSFORMATION TEMPERATURES

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ABSTRACT
Shape memory alloys' usage frequency and areas are increased day to day. It is seen the different type and different characteristics in many industrial areas. Therefore, shape memory alloys, which are intelligent materials, are very fast to develop. The NiTi alloys, from these alloy types, are most commonly used due to their low hysteresis range and biocompatibility. But production costs and difficulties have led, investigators to investigate different alloy types. Shape memory alloys which produced with possibly cheaper elements, examined in researchers with looking at their transformation temperatures.

Keywords: *Dsc, NiTi, Shape Memory Alloys*

1. INTRODUCTION

Shape memory alloys (SMA) are materials known as intelligent metals from the past to present day. In the past, SMA's found in various composition ratios of constrained elements are alloyed with many elemental ingredients now (Canbay, 2017). SMA's shed light on future systems and applications at a high level. The technologies that will be developed with unique features will provide great advantages and their usage will be necessary. High strength, biocompatibility, high wear resistance, high corrosion resistance, working in high temperature and pressure, elasticity ductility etc. intelligent metal alloys are made depending on the needs of the sectors. Healthcare field, defense, and military fields, mechanical systems, automotive sectors etc. (Canbay *et al.*, 2014; Canbay, 2017; Canbay *et al.*, 2017; Canbay *et al.*, 2018). SMA's are required to be developed and used in the fields. Producing SMA's according to the needs of the areas to be used will be the best course of approachment. In order to meet the requirements of the application areas of SMA materials, the alloys must be full-featured and very diverse. Once the SMA's are approached, technology and sectors will be advantageous and the work on these intelligent materials will become more important. The SMA's are a very valuable issue for the Research & Development area. Considering the advantages and convenience of intelligent materials, it is a bright field of materials that many industries in the manufacturing and the business world will not spare their investments and supports (Eskil *et al.*, 2015). SMA's have a certain high temperature phase and low temperature phase according to their element proportion that they contain. The high temperature phase is called the austenite phase, the low temperature phase is called the martensite phase. According to the phase temperature limits, it is determined at which temperature degree the shape memory conversion. This phase change is due to solid-state phase change. In general, the memory-trained shape will talk about memory formation; The SMA material is subjected to shape training. This is another issue that needs to be addressed in more detail (Ozkul *et al*., 2017). However, in the rough description of the work, the shape desired to be taken into memory is usually placed in a mold and heated to a high temperature austenite phase under tension. The alloyed material is converted to the low temperature martensite phase by shock cooling after heating to the austenite phase (Aldas *et al.*, 2014). This cycle is repeated according to the type of material and the methods have differed one-way or two-way. After this process, the SMA will save it in the memory, which is determined in advance of the applied processes. After this step, heat, stress, or both subjected to the plastic deformation that has been exposed and the shape changes back to the SMA as it was recorded in the memory when heated from high to the high temperature austenite phase. It takes its place in the group of intelligent materials (Canbay *et al.*, 2014). It has been stated that the SHA's have various advantageous properties according to the proportion of the elements they contain. Today, many test and screening systems are used in determining these properties. The most common of these is the differential scanning calorimetry (DSC). The DSC test is an important test for determining the temperature points and boundaries of the austenite and martensite phases, which are very important in the memory acquisition of SMA's. The results of DSC scanning of various alloys of elements such as nickel, manganese, gallium, iron, aluminum, and tin have been examined in the literature review. The start and finish temperatures of the austenite and martensite phases were determined. The effect of element contents on phase transformation temperatures was investigated (Aldas *et al.*, 2016).

The austenite-initiation temperature (A_s) is the temperature at which this transformation begins, and the austenite-final temperature (A_f) is the temperature at which this transformation is complete. When the SMA heats up, the contract starts and returns to its original state. This conversion is possible even at high applied loads and, therefore, results in a high energy density of the trigger. During the cooling process, the transformation starts at the martensite starting temperature (M_s) and completes when the martensite reaches the finishing temperature (M_f) (Buehler *et al.*, 1963). Martensite is called the highest temperature M_d that can be caused by residual stress, and when it is above this temperature, SMA permanently deforms like ordinary metallic materials (Duerig *et al.*, 1994). These deforming effects, known as SMA and pseudo elasticity (or super elasticity), can be categorized according to three-dimensional memory properties:

- One-way shape memory effect (OWSME): The unidirectional SMA (SMA) maintains a deformed condition after removing an external force and then returns to its original state upon heating.
- Two-way shape memory effect (TWSME) or reversible SME: In addition to the one-sided effect, bi-directional SMA (TWSMA) can remember both high and low temperature shape. Often the recovery provided by OWSMA for the same material (Schroeder *et al.*, 1977; Huang *et al.*, 2000) yields about half of the water, and this stress tends to deteriorate quickly, especially at high temperatures (Ma *et al.*, 2010). For this reason, OWSMA offers a more reliable and economical solution (Stöckel 1995).
- Pseudo elasticity (PE) or Super elasticity (SE): The SMA returns to its original shape after applying the mechanical load without the need for any thermal activation at temperatures between A_f and M_d.

In addition to the TWSME material above, the prejudicial OWSMA actuator can also function as a 'mechanical TWSME' at a macroscopic (structural) level; more robust, reliable, and widely applied in many engineering applications (Sun *et al.*, 2012). This feature is important and should be considered carefully when selecting SMA materials for targeted applications. For example, a small hysteresis is needed for applications where rapid movement is necessary (robotic applications) (Liu, 2010). The physical and mechanical properties of some SMAs also vary between these two phases, such as Young's modulus, electrical resistance, thermal conductivity, and thermal expansion coefficient (Mihálcz, 2001; Mertmann *et al.*, 2008; Sreekumar *et al.*, 2009). The austenite structure is rigid and has a high Young's modulus. The martensite structure is softer. It can easily deform with the external load (Hodgson *et al.*, 1990; Mihálcz, 2001).

There are three varieties of SMA. These alloys are listed in the literature as NiTi, copper based and iron

based. The most capable of these alloy types is NiTi alloys. Because these alloy types have biocompatibility, they are used in many fields, especially in the field of medicine. Copper-based SMA is the closest to this type of alloy. But there is no popular. Iron-based SHA is the weakest type in this group because they have high hysteresis. In our study, the data of alloy types which may be alternative to NiTi-based SMA will be examined. The temperature transformation points of the austenite and martensite phases of the samples were determined and analyzed on the table and the thermal properties of the shape memory alloys were obtained. All text should be left and right justified. Footnotes and underlines are not allowed.

2. LITERATURE REVIEW

The starting and ending temperatures of the austenite high temperature phase and the martensite low temperature phase are determined and tabulated in the literature review. The bibliographic numbers of the literature search of the thermal values of SMA's are listed at the beginning of the table as (Kainuma *et al.,* 1996; Jiang *et al.,* 2002; Jiang *et al.,* 2003; Wu *et al.,* 2003; Koho *et al.,* 2004; Lanska *et al.,* 2004; Glavatskyy *et al.,* 2006; Koyama *et al.,* 2006; Babita *et al.,* 2007; Santos *et al.,* 2008; Aksoy *et al.,* 2009; Wu *et al.,* 2011; Zheng *et al.,* 2011; Turabi *et al.,* 2016; Caputo *et al.,* 2017; Mostafaei *et al.,* 2017). The transformation temperatures obtained by different element contributions of Ni and Mn-based SMA materials are shown in Table 1.

2.1. Evaluation of Literature Review

In the direction of information from the source if we evaluate the change of austenite and martensite starting end temperature points by changing atomic ratios of nickel, manganese and aluminum elements, In the first sample, nickel and manganese were alloyed at 50 percent and specific temperature points were obtained. It has been observed that the austenite and martensite phase change temperatures are lowered when aluminum is added to this alloy and the manganese proportion is reduced (with the nickel ratio being kept constant). It is observed that when the aluminum ratio is kept constant and the nickel ratio is increased and the manganese ratio is decreased, the phase change temperatures are increased (Kainuma *et al.*, 1996).

Increasing the tin ratio in nickel, manganese and tin alloys has clearly reduced the phase conversion temperature (Koyama *et al.,* 2006; Santos *et al.*, 2008; Zheng *et al.*, 2011; Turabi *et al.*, 2016).

Nickel, manganese and antimony triple alloys have been investigated, and when the antimony ratio in the alloy is reduced, the transformation temperatures of the austenite and martensite phases have increased at a high rate. As a result of this observation, antimony addition reduces the high conversion temperatures (Aksoy *et al.*, 2009).

Nickel, manganese, and gallium ternary alloys were added to the dysprosium element and the effects on the temperature values were observed. When the dysprosium element increased, the phase transformation temperatures increased (Babita *et al.*, 2007).

Nickel, manganese, gallium triple alloy system is added to the silicium element. As the silicium ratio increased, the phase transformation temperatures decreased. When cobalt element is added instead of silicium, cobaltite phase transformation temperatures are lowered in the same way and the austenite and martensite start-finish transformation temperatures are increased by increasing the nickel ratio (Glavatskyy *et al.*, 2006).

Table 1. Transformation temperatures obtained by different element contributions of Ni and Mn based shape memory alloy materials

Ref.	Ni (at.%)	Mn (at.%)	Ga (at.%)	Fe (at.%)	In (at.%)	Si (at.%)	Co (at.%)	Dy (at.%)	Al (at.%)	Sn (at.%)	Sb (at.%)	In (at.%)	Co (at.%)	M_s (°C)	M_f (°C)	A_s (°C)	A_f (°C)
(Wu and Yang, 2003)	50,19	24,71	25,1											-118,5	-126,6	-106	-85
	50,69	23,07	26,24											-146,1	-148,5	-142	-132
	50,33	23,87	25,8											-116,2	-151,3	-132	-124
	50,33	24,38	25,29											-115,5	-129,5	-100	-88
	50,49	24,22	25,28											-76,5	-89,4	-65	-50
	50,28	24,77	24,96											-79,3	-86,6	-69	-60
	50,34	24,8	24,86											-69,3	-80,8	-60	-50
	50,36	24,88	24,75											-65,2	-85,3	-58	-45
	50,56	24,57	24,87											-70,1	-87,5	-59	-43
	50,61	24,84	24,55											-41,9	-58,2	-38	-22
	50,41	25,26	24,33											-55,7	-72,2	-47	-36
	51,56	23,43	25,02											-33,9	-50,4	-23	-9
	51,12	24,3	24,58											-48,8	-61,4	-47	-32
	51,93	23,07	25,01											-32,9	-47,8	-22	-5
	50,98	24,83	24,19											-27,5	-38,5	-17	-6
	50,4	25,85	23,75											-33,1	-45,4	-24	-16
	51,27	24,49	24,24											-16,5	-33,4	-8	12
	51,38	24,81	23,81											-2	-12,2	4	20
	51,19	25,2	23,73											12,5	-17	16	35
	52,84	22,44	24,72											2,7	-13,8	14	28
	53,23	21,85	24,92											7,1	-4,3	20	31
	50,46	26,74	22,8											-7,8	-19,3	6	13
	51,71	24,84	23,45											22,9	5,3	24	40
	50,39	27,77	21,84											26	15,7	30	42
	52,29	24,59	23,12											37,6	30,4	46	50
	52,14	25,16	22,67											58,4	38,8	64	82
	52,54	24,78	22,68											59,4	41,4	53	73
	52,63	24,73	22,64											54,5	40	58	74
	55,78	19,52	24,7											92,2	74,8	102	120

	50,48	28,87	20,65											66	36,8	47	76
	52,84	24,82	22,34											74,3	54,3	68	88
	53,45	24,07	22,48											77,6	55,8	82	104
	53,26	24,68	22,06											100,7	66,7	100	121
	50,37	29,79	19,84											82,2	63,5	80	98
	53,64	24,56	21,82											114,7	80,6	124	135
	53,71	25,27	21,02											158,5	117,2	143	177
	54,15	24,88	20,97											185,3	178,6	202	217
(Jiang *et al.*, 2002)	53	25	22											109	97	116	134
(Jiang *et al.*, 2003)	53	22	25											-4	-14	2	16
(Babita *et al.*, 2007)	50	29	20,9					0,1						66,1	58,9	63	71
	50	29	20,5					0,5						71,2	66,2	71	76
	48	29	20					1						75,9	-28,2	76	80
	49	29	19					2						126,2	116,3	124	132
(Glavatskyy *et al.*, 2006)	47,9	26,1	26											39	38	52	52
	49,7	28,7	21,6											32	30	38	41
	50,5	28,2	21,3											38	34	41	47
	51,4	27,2	21,4											78	72	80	86
	49,9	28	21,6			0,5								17	12	20	25
	50	28,8	20,6			0,6								28	-10	-3	36
	50,4	28,8	19,8			1								25	-5	3	32
	49,6	27,7	20,6			2,1								-128	-136	-111	-103
	48,6	24,8	22,9		3,4									6	-17	-3	16
	51,7	28,5	15,6		4,2									-95	-105	-73	-70
	46,6	25,8	26,8				1,7							-7	-12	-6	0
	43,5	27,9	22,8				5,8							-56	-60	-51	-46
	50	29	18,8				2,2							223	211	224	237
	47,3	25,9	20,4	6,4										13	1	20	30
	49,4	27,5	21,3	1,8										43	39	54	59
	50,9	20,2	23,7	5,2										7	2	6	13
	51,3	14,4	26,3	8										86	79	88	101
	51,8	24,3	23,2	0,7										29	11	21	31
	52,1	23	24,2	0,7										30	0	20	25

(Koho *et al.*, 2004)	51,7	24,4	22,7	1,2										53	34	41	62
	47,3	30,3	20,3	2,1										53	32	42	61
	48,9	29	19,5	2,6										65	52	53	76
	48,8	29,2	20,1	1,9										45	27	49	64
	48,6	27,5	21,6	2,3										31	22	33	41
	48,9	26,2	22,6	2,3										57	45	58	70
	49,4	27,9	20,3											54	42	54	59
	50,2	27,4	21,1											61	50	63	77
	49,6	28,3	20,7											53	36	48	64
	50,1	28,2	20,9	0,8										44	28	40	64
	49,2	29,6	21,2											31	28	35	38
	52,2	27,3	20,6											132	112	102	122
(Lanska *et al.*, 2004)	50,7	28,4	20,9											61	52	66	72
	50,7	28,3	21											57	50	65	70
	50,7	27,8	21,5											52	50	58	61
	50,6	28,5	20,9											60	58	66	68
	50	29,8	20,2											71	67	74	78
	50	28,9	21,1											48	38	47	57
	49,9	29,9	20,2											71	65	77	81
	49,7	29,1	21,2											38	36	46	48
	49,6	29,2	21,2											30	28	36	36
	49,2	30,6	20,2											55	50	60	64
	49,1	30,7	20,2											51	48	59	62
	49	30,3	20,7											39	36	45	50
	48,5	30,3	21,2											29	26	32	35
	51	28,5	20,5											83	77	81	87
	50,5	29,4	20,1											78	70	75	84
	49,5	30,3	20,2											68	64	71	75
	48,8	31,4	19,8											64	60	65	69
	54,9	23,8	21,3											286	268	295	314
	54	24,7	21,3											224	214	225	237
	53,9	24,4	21,7											257	251	278	287
	53,7	26,4	19,9											250	239	265	273

	53,3	24,6	22,1											192	186	195	203
	52,9	25	22,1											75	71	81	90
	52,8	25,7	21,5											117	94	104	131
	52,7	26	21,3											161	143	151	173
	52,4	25,6	22											150	141	151	161
	52,3	27,4	20,3											125	118	130	135
	51,7	27,7	20,6											110	96	108	121
	51,5	26,8	21,7											120	101	107	127
	51,2	27,4	21,4											98	93	98	102
	51	28,7	20,3											106	93	103	112
	50,5	30,4	19,1											118	103	110	124
	47	33,1	19,9											53	50	56	58
(Santos *et al.*, 2008)	50,55	36,33								13,12				-55	-66	-49	-41
(Wu *et al.*, 2011)	37	50										10	3	-87	-120	-94	-61
(Turabi *et al.*, 2016)	42,1	48,7								9,2				-6	-16	-6	4
(Kainuma *et al.*, 1996)	50	50												674	660	707	719
	50	46							4					589	567	593	608
	50	42							8					473	459	485	503
	50	38							12					341	285	304	368
	50	34							16					191	128	134	192
	50	30							20					-22	-34	-12	-4
	44	46							10					268	259	348	362
	45	40							15					116	81	94	119
	55	30							15					386	378	433	449
(Zheng *et al.*, 2011)	49	39								12				-13	-34	1	22
(Koyama *et al.*, 2006)	50	36								14				-53	-63	-33	-23
(Aksoy *et al.*, 2009)	50,3	35,9									13,8			3	-8	2	17
	50,2	36,6									13,2			4	-3	7	18
	51,5	36									12,5			73	65	76	85
	50,3	39,6									10,1			171	95	107	184
	51,9	42,7									5,4			436	348	359	468
(Caputo and Solomon 2017)	49,5	27,8	22,7											36,9	17,1	33,9	57,6
(Mostafaei *et al.*, 2017)	49,6	30,8	19,6											36	31,5	42	46,5

3. CONCLUSION

Shape memory alloys are defined undeniably positioned in the technology. However, in terms of production costs, it is necessary to search for alloy types that will become an alternative to high-grade alloys such as NiTi and to present the service of humanity. From this point of view, successful studies with elements such as manganese, which can be provided as cheaper than the titanium element in nickel-based SHA, have been investigated. It has been found that in the determined thermal phase temperature transformations, the alloys' high nickel, manganese and gallium ratios are largely determinative. As a result of these studies, a wide range of transformation temperatures have been identified and found to be open to Research & Development. These types of alloys that provide the wide range of conversion can respond to many needs.

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