THERMAL PROPERTIES OF COPPER BASE SHAPE MEMORY ALLOY

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ABSTRACT

The mechanical properties and microstructure of copper base shape memory alloys are relatively well known, while data on thermal properties (thermal conductivity, specific heat, and temperature conductivity) are not available. In the frame of our investigation work thermal properties of rapidly solidified Cu-Al-Ni-Mn alloy were determined.

As the first part of the work, a study and evaluation of the operation of the device for determining the thermal properties of Hot Disk TPS 2200, today one of the more modern and high-quality instruments for determining thermal properties has been carried out.

In the second part of the work, the measurements and analysis of thermal properties of rapidly solidified Cu-Al-Ni-Mn shape memory alloy in accordance with the standard ISO 22007-2 at ambient and elevated temperatures have been done.

1. INTRODUCTION

Shape memory alloys (SMA) are relatively a new class of advanced functional materials that are able to memorize and recover their original shape after being significantly deformed from heating over the phase transformation temperature [1].

The main advantage of Cu-based SMA is their low price compared to other SMA. The properties of Cu-Al-Ni alloys are superior to those of Cu-Zn-Al alloys due to their wide range of useful transformation temperatures and small hysteresis. Although Cu-Al-Ni alloys have better thermal and electrical stability and higher operating temperatures, their practical applications are sometimes restricted by very small shape changes due to their poor workability and susceptibility to brittle intergranular cracks [2]. Their very high elastic anisotropy and large grain size cause brittle and poor mechanical properties owing to the high degree of order in the parent phase. Typically composition of Cu-Al-Ni SMA is in the range Cu-(13-15 m. %)Al-(3-4.5 m. %)Ni [3]. Adding some alloying elements

such as Mn, Fe, Ti, Zr, B, etc. to the alloys can significantly improve their ductility and other properties which modify their operating temperatures [4,5].
In the frame of our investigation, we have investigated the thermal properties of rapidly solidified Cu-Al-Ni-Mn shape memory alloy [6] produced by the melt-spinning procedure (Figure 1). The chemical composition of the testing Cu-Al-Ni-Mn alloy is in Table 1.

Table 1. Chemical composition of the testing Cu-Al-Ni-Mn alloy (in m.%)

Al	Ni	Mn	Cu
12.7	4.2	2.4	rest

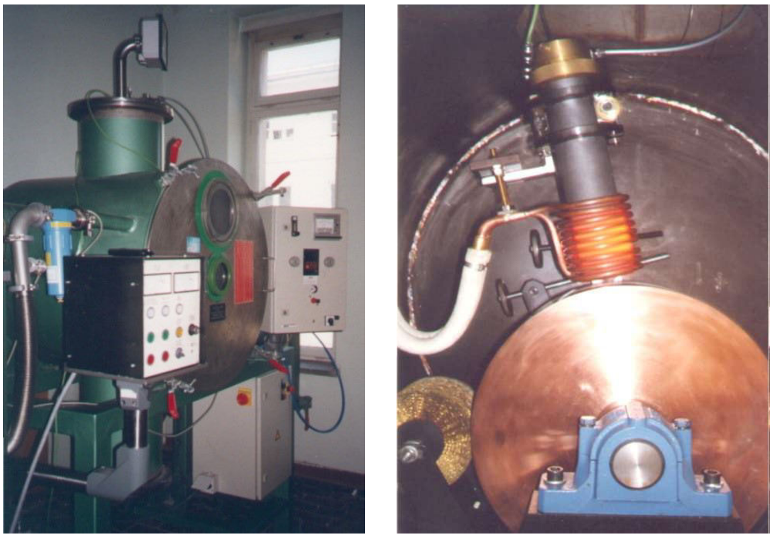
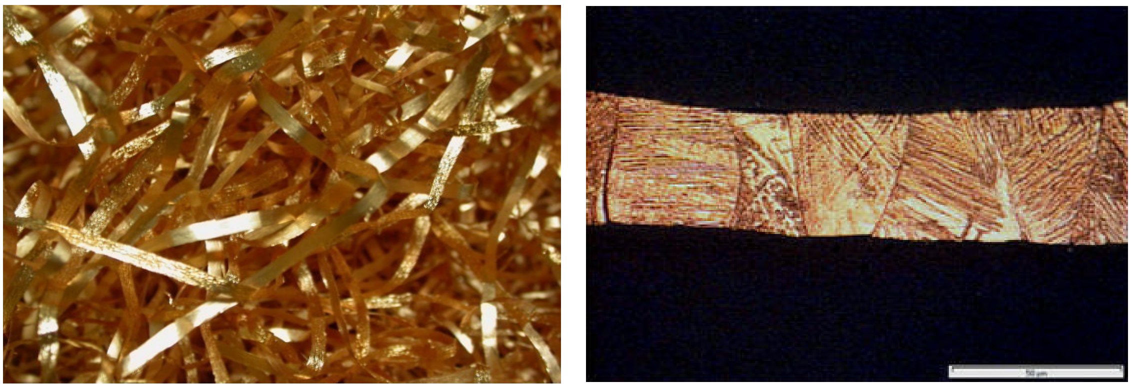


Figure 1. Melt spinner at the Faculty of Natural Sciences and the Engineering University of Ljubljana [7]

Single Roll Melt Spinning is the most commonly used process for the production of rapidly solidified thin metal foils or ribbons with amorphous, microcrystalline, or even combined microstructure. In this type of process, a molten material is introduced onto the surface of the spinning wheel, where a melted puddle is formed, and as a final result metal ribbons are formed (Figure 2).



a) b)

Figure 2. Rapidly solidified Cu-Al-Ni-Mn shape memory alloy thin ribbons (a), microstructure (b)

Figure 3. Disks from the ground and molded rapidly solidified Cu-Al-Ni-Mn shape memory alloy

The final products are in the form of thin and narrow ribbons, which could be in further production steps subjected to milling and molded into useful shapes by different methods of powder metallurgy. In our case, we have made disks from the ground and molded alloys (Figure 3). From them, testing samples to perform measurements of thermal properties of dimensions Ø40 x 13 mm have been done.

2. THERMAL PROPERTIES MEASUREMENT

In our research, we used one of the most advanced instruments for determining the thermal properties, Hot Disk TPS 2200, a product of Hot Disk AB Company, Gothenburg, Sweden (Figure 4) [8].

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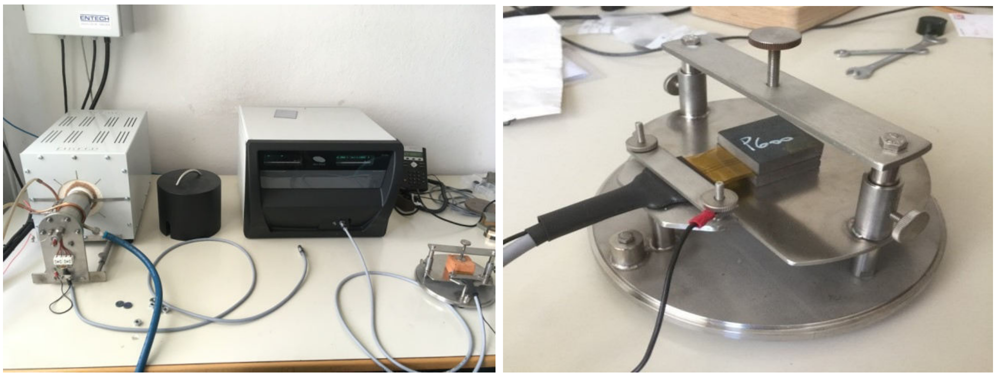


a) b)

Figure 4. Instrument Hot Disk TPS 2200 (a). Measuring sensor sandwiched between two halves of a sample during measurement (b)

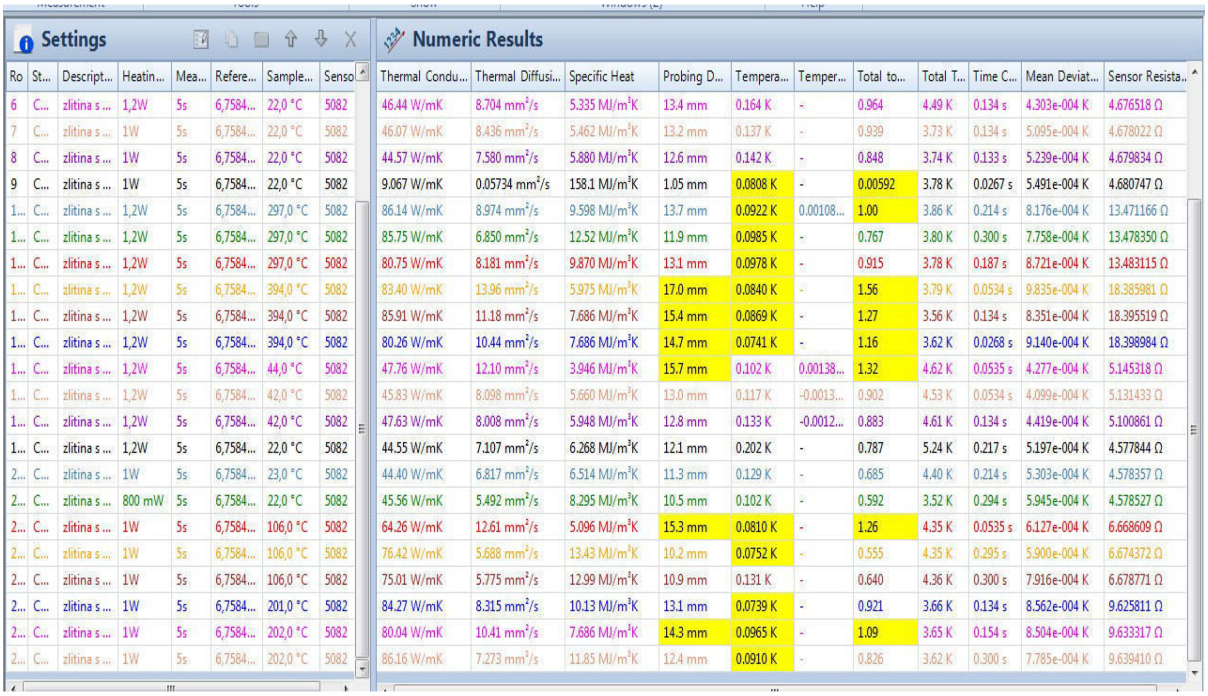
The instrument can be used for determining the thermal properties of various materials including pure metals, alloys, minerals, ceramics, plastics, glasses, powders, and viscous liquids with thermal conductivity in the range from 0.01 to 500 W/mK, thermal diffusivity from 0.01 to 300 mm^2/s and heat capacity up to 5 MJ/m^3K. Measurements can be performed in a temperature interval between -50°C to 750 °C [9].

The hot disk measuring method is a transient plane source technique (TPS). Based on the theory of TPS, the instrument utilizes a sensor element in the shape of a 10 μm thick double spiral, made by etching from pure nickel foil. Spiral is mechanically strengthened and electrically insulated on both sides by thin polyimide foil (Kapton ®Du Pont) for measurements up to 300 °C or mica foil for measurements up to 750 °C.

Sensor acts both as a precise heat source and resistance thermometer for recording the time-dependent temperature increase. During the measurement of solids, encapsulated Ni-sensor is sandwiched between two halves of the sample and constant precise pre-set heating power is released by the sensor, followed by 200 resistance recording in a pre-set measuring time, from which the relation between time and temperature change is established. Based on the time-dependent temperature increase of the sensor, the thermal properties of the tested material are calculated.

3. EXPERIMENTAL WORK

Measurements and analysis of thermal properties of testing samples from the testing rapidly solidified copper base shape memory alloy were performed in accordance with ISO 22007-2 standard [10] in the Laboratory for Thermotechnical Measurements, Faculty of Natural Sciences and Engineering, University of Ljubljana. In Figure 5 complete data of thermal properties measurements are presented.



Ro	St...	Descript...	Heatin...	Mea...	Refere...	Sample...	Senso	Thermal Condu...	Thermal Diffusi...	Specific Heat	Probing D...	Tempera...	Temper...	Total to...	Total T...	Time C...	Mean Deviat...	Sensor Resista...
6	C...	zlitina s ...	1,2W	5s	6,7584...	22,0 °C	5082	46.44 W/mK	8.704 mm^2/s	5.335 MJ/m^{3}K	13.4 mm	0.164 K	-	0.964	4.49 K	0.134 s	4.303e-004 K	4.676518 Ω
7	C...	zlitina s ...	1W	5s	6,7584...	22,0 °C	5082	46.07 W/mK	8.436 mm^2/s	5.462 MJ/m^{3}K	13.2 mm	0.137 K	-	0.939	3.73 K	0.134 s	5.095e-004 K	4.678022 Ω
8	C...	zlitina s ...	1W	5s	6,7584...	22,0 °C	5082	44.57 W/mK	7.580 mm^2/s	5.880 MJ/m^{3}K	12.6 mm	0.142 K	-	0.848	3.74 K	0.133 s	5.239e-004 K	4.679834 Ω
9	C...	zlitina s ...	1W	5s	6,7584...	22,0 °C	5082	9.067 W/mK	0.05734 mm^2/s	158.1 MJ/m^{3}K	1.05 mm	0.0808 K	-	0.00592	3.78 K	0.0267 s	5.491e-004 K	4.680747 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	297,0 °C	5082	86.14 W/mK	8.974 mm^2/s	9.598 MJ/m^{3}K	13.7 mm	0.0922 K	0.00108...	1.00	3.86 K	0.214 s	8.176e-004 K	13.471166 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	297,0 °C	5082	85.75 W/mK	6.850 mm^2/s	12.52 MJ/m^{3}K	11.9 mm	0.0985 K	-	0.767	3.80 K	0.300 s	7.758e-004 K	13.478350 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	297,0 °C	5082	80.75 W/mK	8.181 mm^2/s	9.870 MJ/m^{3}K	13.1 mm	0.0978 K	-	0.915	3.78 K	0.187 s	8.721e-004 K	13.483115 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	394,0 °C	5082	83.40 W/mK	13.96 mm^2/s	5.975 MJ/m^{3}K	17.0 mm	0.0840 K	-	1.56	3.79 K	0.0534 s	9.835e-004 K	18.385981 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	394,0 °C	5082	85.91 W/mK	11.18 mm^2/s	7.686 MJ/m^{3}K	15.4 mm	0.0869 K	-	1.27	3.56 K	0.134 s	8.351e-004 K	18.395519 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	394,0 °C	5082	80.26 W/mK	10.44 mm^2/s	7.686 MJ/m^{3}K	14.7 mm	0.0741 K	-	1.16	3.62 K	0.0268 s	9.140e-004 K	18.398984 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	44,0 °C	5082	47.76 W/mK	12.10 mm^2/s	3.946 MJ/m^{3}K	15.7 mm	0.102 K	0.00138...	1.32	4.62 K	0.0535 s	4.277e-004 K	5.145318 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	42,0 °C	5082	45.83 W/mK	8.098 mm^2/s	5.660 MJ/m^{3}K	13.0 mm	0.117 K	-0.0013...	0.902	4.53 K	0.0534 s	4.099e-004 K	5.131433 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	42,0 °C	5082	47.63 W/mK	8.008 mm^2/s	5.948 MJ/m^{3}K	12.8 mm	0.133 K	-0.0012...	0.883	4.61 K	0.134 s	4.419e-004 K	5.100861 Ω
1...	C...	zlitina s ...	1,2W	5s	6,7584...	22,0 °C	5082	44.55 W/mK	7.107 mm^2/s	6.268 MJ/m^{3}K	12.1 mm	0.202 K	-	0.787	5.24 K	0.217 s	5.197e-004 K	4.577844 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	23,0 °C	5082	44.40 W/mK	6.817 mm^2/s	6.514 MJ/m^{3}K	11.3 mm	0.129 K	-	0.685	4.40 K	0.214 s	5.303e-004 K	4.578357 Ω
2...	C...	zlitina s ...	800 mW	5s	6,7584...	22,0 °C	5082	45.56 W/mK	5.492 mm^2/s	8.295 MJ/m^{3}K	10.5 mm	0.102 K	-	0.592	3.52 K	0.294 s	5.945e-004 K	4.578527 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	106,0 °C	5082	64.26 W/mK	12.61 mm^2/s	5.096 MJ/m^{3}K	15.3 mm	0.0810 K	-	1.26	4.35 K	0.0535 s	6.127e-004 K	6.668609 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	106,0 °C	5082	76.42 W/mK	5.688 mm^2/s	13.43 MJ/m^{3}K	10.2 mm	0.0752 K	-	0.555	4.35 K	0.295 s	5.900e-004 K	6.674372 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	106,0 °C	5082	75.01 W/mK	5.775 mm^2/s	12.99 MJ/m^{3}K	10.9 mm	0.131 K	-	0.640	4.36 K	0.300 s	7.916e-004 K	6.678771 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	201,0 °C	5082	84.27 W/mK	8.315 mm^2/s	10.13 MJ/m^{3}K	13.1 mm	0.0739 K	-	0.921	3.66 K	0.134 s	8.562e-004 K	9.625811 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	202,0 °C	5082	80.04 W/mK	10.41 mm^2/s	7.686 MJ/m^{3}K	14.3 mm	0.0965 K	-	1.09	3.65 K	0.154 s	8.504e-004 K	9.633317 Ω
2...	C...	zlitina s ...	1W	5s	6,7584...	202,0 °C	5082	86.16 W/mK	7.273 mm^2/s	11.85 MJ/m^{3}K	12.4 mm	0.0910 K	-	0.826	3.62 K	0.300 s	7.785e-004 K	9.639410 Ω

Figure 5. Data of TPS measurements

In Table 2 thermal properties (thermal conductivity, specific heat, and temperature conductivity) of analysed rapidly solidified Cu-Al-Ni-Mn shape memory alloy at ambient temperature (approx. 22 ^{o}C) are presented.

Table 2. Thermal properties of analysed Cu-Al-Ni -Mn shape memory alloy at ambient temperature

	Cu-Al-Ni-Mn
Thermal conductivity	45.30 W/mK
Specific heat	6.29 MJ/m^{3}K
Temperature conductivity	7.36 mm^2/s

Thermal conductivity of analysed Cu-Al-Ni-Mn shape memory alloy on the temperature interval between ambient temperature (approx. 22 ^{o}C) and temperature 400 ^{o}C growing up from 45.30 W/mK to 86.45 W/mK (Figure 6).

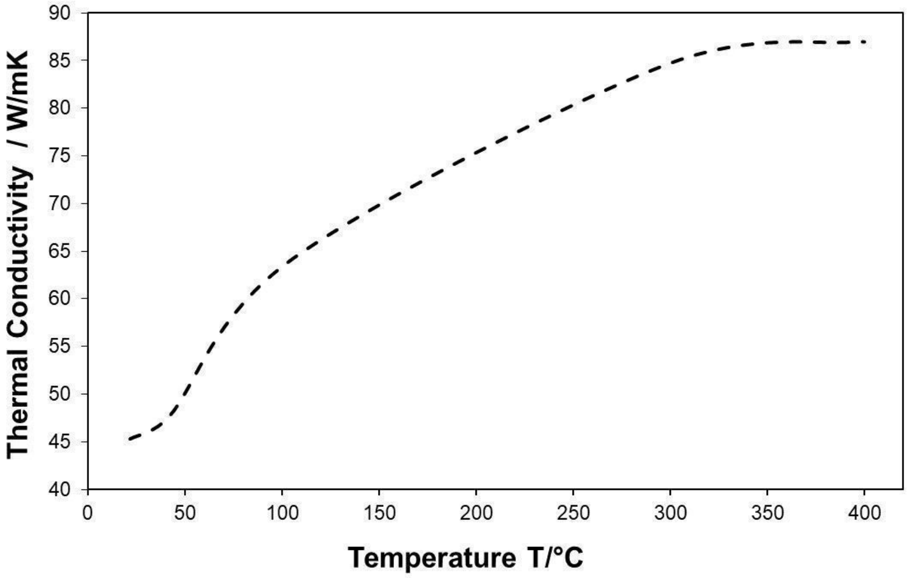


Figure 6. Thermal conductivity at elevated temperatures

4. CONCLUSIONS

In the frame of investigation thermal properties of rapidly solidified Cu-Al-Ni-Mn shape memory alloy were determined. The measurements and analysis of thermal properties of rapidly solidified Cu-Al-Ni-Mn shape memory alloy have been done in accordance with the standard ISO 22007-2 at ambient and elevated temperatures.

The values of thermal properties of Cu-Al-Ni-Mn alloy at ambient temperature (approximately 22 °C) are:

thermal conductivity 45.30 W/mK,

specific heat 6.29 MJ/m^3K, and

temperature conductivity 7.36 mm^2/s.

We found that investigated rapidly solidified Cu-Al-Ni-Mn shape memory alloy at ambient temperature has almost 100 % lower heat conductivity at a temperature of 400 ^{o}C.

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