Effect of Sintering Temperature on the Mechanical Properties of Vacuum Sintered Co-(Zn)-Ni-Al Alloys

G. Johnsy Arputhavalli1*, S. Agilan1, S. Jebasingh2, S. Vijay Joseph3
1Department of Physics, Coimbatore Institute of Technology, Coimbatore, India. 
2Department of Mathematics, Karunya Institute of Technology and Sciences, Coimbatore, India.
3Department of Mechanical Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.

Abstract:
In the present study, the wear resistance behavior and the microhardness of the Co38Ni35Al27 and Co35Zn10Ni32Al23 ferromagnetic shape memory alloys (FSMAs) were investigated. The alloy samples were prepared by powder metallurgy method along with the vacuum sintering technique. The major aim is to prepare an alloy with high wear resistance having remarkable microhardness suitable for the sustainable shape memory alloy. The wear test report shows that the wear resistance is high for the sample sintered at 673 K and it gradually reduces when the sintering temperature decreases. The result also shows that the inclusion of zinc in the alloy increases the wear rate. The maximum hardness value of 126 HV was observed in Co38Ni35Al27 sample sintered at 673 K for 8 hrs because of its minimal porosity.

Keywords: Cobalt Nickel Aluminium alloys; Powder metallurgy; Vacuum sintering; Mechanical properties.

1. Introduction

Developing a high wear resistive and good micro hardness alloy is of enormous interest in the field of actuator applications. To achieve a remarkable improvement in wear resistance and microhardness, the powder metallurgy method has been chosen [1, 2]. Co-Ni-Al alloy is one of the novels and fascinating group of materials in the ferromagnetic shape memory alloy (FSMA) system. Its remarkable properties are good ductility, great control over martensitic transformation temperature, higher transformation stresses, the high magnetic field induced strain (MFIS), and enhanced wear resistance [3, 4]. These properties indicate that it is the most significant alloy for sensors and actuator based applications. The high content cobalt-based Co-Ni-Al alloy has two-phase structures. The B2 phase (β-phase), which is firm and brittle that experiences martensitic transformation into tetragonal L01 structure (γ’-phase) [5-7]. The microstructure behavior of Co38Ni35Al27 composition proves its ductility by its crystalline matrix structure (β + γ phase) [6, 7]. Due to high wear resistance, the maximum deformation achieved so far in Co-Ni-Al alloy is approximately 10% in the external magnetic field [8], which is believed that it will act as a substitute to single-crystalline Ni–Mn–Ga alloys for the magnetic shape memory (MSM) application [9-12]. The failure in the
mechanical properties of Ni-Mn-Ga [13], urging us to focus on the mechanical properties of Co-Ni-Al alloy.

Powder metallurgy method is a widely used method than the traditional casting methods to prepare high purity samples for studying mechanical properties. The samples prepared by the powder metallurgy method can be conveniently cast into required dimensions with a fine microstructure. The refined microstructure is obtained by the ball milling process and the range of solid solubility has been augmented in the samples [14]. After 80 h of milling, nano-crystalline fcc was formed in Co (Ni, Al) solid solution. Further, the sample was subjected to densification using vacuum hot pressing [15] and two-phase $\gamma$ and L$_{10}$ microstructure are obtained. In the previous studies, the effect of sintering parameters on phase transformation behavior, porosity reduction, microstructure, domain structure of the vacuum sintered alloy has been studied [16]. Also, the same authors have studied the wear resistance behavior and the microhardness test for the spark plasma sintered Co-Ni-Al alloy [17].

In the present study, the effect of vacuum sintering temperature on the wear resistance behavior, its microstructural characteristics after being worn out and the hardness have been studied for the Co$_{38}$Ni$_{35}$Al$_{27}$ and Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloy systems. The alloy samples were ball milled, compacted and vacuum sintered using powder metallurgy method. As it is known that the characteristics of high cobalt content in both the alloy system would lower the martensite start (Ms) and martensite finish (Mf) temperatures. The Mf of Co$_{38}$Ni$_{35}$Al$_{27}$ alloy and Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloy was found to be below the room temperature. Therefore the conventional heat treatment not makes the grade have phase transformation from austenite to martensite. Because of this reason, for the present study the vacuum sintering method was chosen and the temperature range has been fixed well below the melting point of aluminium. The two main challenges in the new vacuum sintering method increase in the wear resistance of the alloy and improvement in the hardness of the alloy.

2. Materials and Experimental Procedures

2.1 Fabrication of Alloys

The raw materials zinc, cobalt, nickel, and aluminium, procured from Sigma-Aldrich, having a high purity level of 99.99 % were used for preparing the sample. The pure raw materials were mixed under the required stoichiometric compositions of Co-Ni-Al and Co-Zn-Ni-Al (in at %). The stoichiometric composition of Co-Ni-Al and Co-Zn-Ni-Al alloy taken for the present study are listed in the Tab. 1. The compounds were subjected to ball milling for 12 h at 400 rpm in a high energy planetary mill (Make: RETSCH, Germany) and the ball to powder mass ratio of 10:1 was retained. The mixture was then compacted as pellets using hydraulic press having an optimized axial pressure of 400 M Pa for 15 minutes [17]. The dimensions of the compacted alloy samples are 10 mm diameter with a thickness of around 5mm.

| Samples      | Stoichiometric Composition (at weight%) |
|--------------|-----------------------------------------|
| Co-Ni-Al     | Co$_{38}$Ni$_{35}$Al$_{27}$              |
| Co-Zn-Ni-Al  | Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$     |

The compacted samples were then loaded in alumina boat for vacuum sintering at 353, 473, and 673 K inside a vacuum furnace for approximately 8 hours and then immediately air
quenched. The mechanical properties of the sample were studied using DUCOM pin on the disk wear resistance method and the hardness of the sample was tested using Vicker’s hardness test. The worn-out debris was collected and its composition was studied using energy dispersive X-ray analysis and the surfaces of the worn-out samples were analyzed using field emission scanning electron microscope.

2.2 Wear testing measurement

Wear is the occurrence of elimination of particles on the surface of the sample which is in contact with another solid surface. This phenomenon occurs mostly at the outer surface of the alloy and to overcome the wear of a sample it is better to alter the surface of the existing alloy than using wear-resistant alloys. The wear-resistant property of the sample is tested with a pin-on-disc machine (Model: Wear & Friction Monitor TR-20 supplied by DUCOM) is shown in Fig. 1a for many specimens using dry sliding wear tests.

![Fig. 1. (a) DUCOM pin-on-disc sliding wear machine used to study wear test. (b) Vicker’s hardness testing machine used to study microhardness.](image)

The surface of the pin was made flat to bear the load over its cross-section. The pin was kept in a position against the counterface of the rotating disc (EN31 steel disc) having a rotational speed of 477 rpm with a wear track diameter of 80 mm. The wear test for both the alloy system was conducted under the normal loads of 50 N and a sliding velocity of 2 m/s.

Before testing, the sample was ground with an emery paper of grit size 80. The initial turbulence connected with friction and wear curves is evaded during the Run-in wear stage. The steady-state wear occurs during the last stage. At this stage, the transfer of material from the pin on to the disc occurs and the wear debris settles on the disc. The disc and pin were wiped with ethanol soaked cotton before the test has begun. Also, due care was taken to apply the load in a normal direction.

2.3 Vicker’s Hardness test measurement

Vicker’s hardness testing machine is used to determine the hardness of the samples. Fig. 1b shows the Vicker’s hardness tester instrument used for measuring the microhardness of the samples. A square pyramid is thrust on the surface of the sample causing the material to
suffer deformation. The dimensions of at least three spots were identified and their deformations were measured to obtain the average hardness using the microscope present in the system. The load-independent hardness number can be found from the formula $L/d^2$, where $L$ is the load applied and $d$ is the mean diagonal value of the deformation. The hardness of the sample can be estimated using the formula $H_v = 1.854 L/d^2$.

3. Results and discussion

3.1 Wear Analysis

Fig. 2a shows the wear resistance graph for the Co$_{38}$Ni$_{35}$Al$_{27}$ alloys and Fig. 2b represents the coefficient of friction of Co$_{38}$Ni$_{35}$Al$_{27}$ alloys sintered at 353, 473, and 673 K. Fig. 3a shows the wear resistance graph for the Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloys and Fig. 3b represents the coefficient of friction of Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloys sintered at 353, 473, and 673 K. The wear resistance and the coefficient of friction studies were performed at room temperature for the applied load of 50 N for both the alloys sintered at different temperatures. The tests have been carried out at low speed with a lesser amount of load to minimize the local temperature rise during the experiment.

![Wear resistance graph for Co$_{38}$Ni$_{35}$Al$_{27}$ alloy. (b) Coefficient of friction of the Co$_{38}$Ni$_{35}$Al$_{27}$ alloy sintered at different sintering temperatures (353, 473, and 673 K).](image-url)
At the beginning of the test, the sample undergoes increasing wear rate, due to the process of plastic deformation in the material, later it becomes moderate with an increasing period. At higher temperatures, the less wear rate, and mass loss maybe because of the oxide layer formed on the surface of the alloy during sliding [18]. It was observed that as the sintering temperature increases, for Co38Ni35Al27 alloy, the wear rate decreases from 48 µm to 44 µm and for Co35Zn10Ni32Al23 alloy, the wear rate decreases from 50 µm to 47 µm. It is noted that the Co38Ni35Al27 alloy vacuum sintered at 673 K has a lesser amount of wear rate when compared with the Co35Zn10Ni32Al23 alloy sintered at 673 K alloys. It is also noted that the inclusion of Zn in the Co-Ni-Al alloy system increases the wear rate and decreases the hardness of the sample.

![Graph](image)

**Fig. 3.** (a) Wear resistance graph for Co35Zn10Ni32Al23 alloy. (b) Coefficient of friction of the Co35Zn10Ni32Al23 alloy sintered at different sintering temperatures (353, 473, and 673 K).

The coefficient of friction of Co35Zn10Ni32Al23 alloy was sustained at around 0.2 to 0.8 for up to 200 seconds. But for the Co38Ni35Al27 alloys, the coefficient of friction was gradually increasing from 0 to 1.4 for up to 200 seconds. It is noted that the coefficient of friction is unstable for the Co38Ni35Al27 alloy system with an increasing period. For Co35Zn10Ni32Al23 alloy system, at 353 K sintered sample the friction coefficient shows zigzag like tendencies with an increase in the time period. It is observed that as the sintering temperature increases the coefficient of friction is found to be greater while the wear rate is less.
3.2 Microstructure Analysis

Fig. 4 (a) and (b) show the SEM image of the worn surface of Co\textsubscript{38}Ni\textsubscript{35}Al\textsubscript{27} and Co\textsubscript{35}Zn\textsubscript{10}Ni\textsubscript{32}Al\textsubscript{23} alloy sintered at 673 K. The formation of defects on the surface with the increase in dislocation density found in the wear samples are mainly due to the internal stress developed during sintering.

![SEM image of the worn surface of Co\textsubscript{38}Ni\textsubscript{35}Al\textsubscript{27} alloy and Co\textsubscript{35}Zn\textsubscript{10}Ni\textsubscript{32}Al\textsubscript{23} alloy sintered at 673 K.](image)

**Fig. 4.** SEM image of the worn surface of (a) Co\textsubscript{38}Ni\textsubscript{35}Al\textsubscript{27} alloy, (b) Co\textsubscript{35}Zn\textsubscript{10}Ni\textsubscript{32}Al\textsubscript{23} alloy sintered at 673 K.

![EDAX spectrum of the wear debris of Co\textsubscript{38}Ni\textsubscript{35}Al\textsubscript{27} and Co\textsubscript{35}Zn\textsubscript{10}Ni\textsubscript{32}Al\textsubscript{23} alloys sintered at 673 K.](image)

**Fig. 5.** EDAX spectrum of the wear debris (a) Co\textsubscript{38}Ni\textsubscript{35}Al\textsubscript{27} alloy, (b) Co\textsubscript{35}Zn\textsubscript{10}Ni\textsubscript{32}Al\textsubscript{23} alloy sintered at 673 K.
The alloys sintered at 673 K have less internal stress when compared to low sintering temperatures. The microstructure studies were observed for the alloys sintered at 673 K after wear measurement was performed. It is observed that both the alloys have many pits and grooves on the surface of the sample. This may be due to the improper optimizing parameter during the sintering process. It is also observed from the Co38Ni35Al27 image that, there are few numbers of thin, narrow grooves that were present on the worn-out surface. Most of the grooves which were present along its sliding direction were considered to be the characteristics of abrasive wear. The groves and the pits can be less at lower speeds (< 2 m/s) and at lower loads (< 50 N). While comparing both the alloy system, the Co38Zn10Ni32Al23 alloy has a large number of wide and depth grooves, pits along the sliding direction were observed. This indicates that there may be a slight high degree of plastic deformation observed in the Co38Zn10Ni32Al23 alloy than the Co38Ni35Al27 alloy. Tab. II represents the composition of the wear debris powder of the Co-Ni-Al and Co-Zn-Ni-Al alloy sintered at 673 K. The composition of the alloy debris was measured by EDAX. It is noted that the alloy debris is of the same stoichiometric composition taken for alloying. Fig. 5 (a) and (b) shows the EDAX spectrum of the wear debris of Co38Ni35Al27 and Co38Zn10Ni32Al23 alloy sintered at 673 K.

| Alloy Samples     | Composition (at weight%) |
|-------------------|--------------------------|
| Co-Ni-Al          | Co 38.11                 |
|                   | Ni 34.64                 |
|                   | Al 27.25                 |
| Co-Zn-Ni-Al       | Co 34.84                 |
|                   | Zn 10.03                 |
|                   | Ni 32.41                 |
|                   | Al 22.72                 |

3.3 Density and Microhardness Measurements

The densities of the vacuum sintered samples were measured using an analytical balance with a density measuring kit. Density measurement after sintering and Vicker’s Hardness value for Co38Ni35Al27 and Co35Zn10Ni32Al23 alloys were listed in Tab III. Alloy’s having a higher green density, compacted at 400 MPa when subjected to vacuum sintering attains an average density of 92 %. It is observed that as the vacuum sintering temperature increases there was a rise in density from 92 % to 97.5 % Co38Ni35Al27 and 88 % to 94.9 % for Co35Zn10Ni32Al23 alloy. Also, the Co35Zn10Ni32Al23 samples show a lesser density when compared to Co38Ni35Al27 alloy. The inclusion of Zn in the Co-Ni-Al alloy system may slightly decrease the grain boundary diffusion, which decreases density value and hardness. The further rise in sintering temperature may show a slight variation in the stoichiometric composition of the alloy with less density. Therefore, the vacuum sintering temperature has been set below 700 K. The maximum density value for Co38Ni35Al27 sintered at 673 K was found to be 4.39 g/cc which is equivalent to 97.5 % of the theoretical density.

The microhardness of Co38Ni35Al27 and Co35Zn10Ni32Al23 alloys were determined using Vickers tester. For the static indentation test, 0.50 kgf of the load was applied to the alloy sample which is held perpendicular to the diamond pyramid indenter. An average of five impressions was made on every sample and the average of diagonal lengths (d) of the indentation mark was measured using a calibrated micrometer.
Tab. III Density measurement after sintering and Vicker’s Hardness value for Co$_{38}$Ni$_{35}$Al$_{27}$ and Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloys.

| Sample Name      | Sintering Temperature | Density measurement after sintering (g/cm$^3$) | Average sintered density (% TD) | Average Vicker’s Hardness (HV) |
|------------------|-----------------------|-----------------------------------------------|--------------------------------|-------------------------------|
| Co$_{38}$Ni$_{35}$Al$_{27}$ | 353 K               | 4.161                                         | 92.46                          | 78                            |
|                  | 473 K               | 4.264                                         | 94.75                          | 86                            |
|                  | 673 K               | 4.39                                          | 97.55                          | 126                           |
| Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ | 353 K               | 4.015                                         | 88.24                          | 73                            |
|                  | 473 K               | 4.21                                          | 92.52                          | 79                            |
|                  | 673 K               | 4.318                                         | 94.9                           | 110                           |

Fig. 6. Microhardness graph for Co$_{38}$Ni$_{35}$Al$_{27}$ and Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloy sintered at different sintering temperatures.

The graph is plotted between the Vicker's hardness value and the sintering temperatures for both the alloy samples and is shown in Fig. 6. If the alloy sample is vacuum sintered for a longer period, the retained austenite may get slowly transforms into the martensite phase. Therefore, to retain less amount of austenite, the temperature-time was fixed as 8 hrs. Also, at 673 K, due to the development of compressive stress on the austenite site along with martensite sites, the retained austenite phase finds it difficult to further transform [19]. Therefore, less amount of retained austenite remains in the microstructure which was surrounded by the martensite phase shows improvement in the hardness of the alloy. The maximum hardness of 126 HV was observed in the Co$_{38}$Ni$_{35}$Al$_{27}$ alloy sintered at 673 K for 8 hrs because of minimal porosity.

The hardness of both the alloy system is found to increase with an increase in the sintering temperature which may be due to thermal misfit dislocation happened at the interface, due to which the alloy exhibits the maximum resistance to plastic deformation. It is also noted that the hardness of the ternary Co$_{38}$Ni$_{35}$Al$_{27}$ alloy shows higher hardness value when compared to the quaternary Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloys. The less value for Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ alloys may be due to the size mismatch of Zn sites in the Co, Ni, and Al sites. This also may be due to the effect of the nature of defects, its quantity, and its atomic size. A similar kind of observation was made for Ni$_2$MnGa off-stoichiometric alloys [20].
4. Conclusion

The Co_{38}Ni_{35}Al_{27} and Co_{35}Zn_{10}Ni_{32}Al_{23} polycrystalline alloy samples were prepared through the powder metallurgy technique, which was compacted and sintered after grinding the powder for 12 hours under ball milling. The alloys sintered at different temperatures have been studied for their mechanical properties. The wear resistance behavior of the 673 K vacuum sintered samples of both the alloy system shows a decrease in wear rate with an increase in the coefficient of friction. The worn Co_{38}Ni_{35}Al_{27} alloy sintered at 673 K has few thin and narrow grooves, pits on the surface along the sliding direction. The composition of the alloy debris was the same as that of stoichiometric composition taken for alloying. The hardness of both the alloy system is found to be the increased value at 673 K sintering temperature. This indicates that less amount of retained austenite remains in the microstructure which was surrounded by the martensite phase shows improvement in the hardness of the alloy. The ternary Co_{38}Ni_{35}Al_{27} alloy shows a higher hardness value of 126 HV for the sintered alloy at 673 K.

Acknowledgments

The authors wish to acknowledge the Centre for research in metallurgy (CRM), Department of mechanical, Karunya Institute of Technology and Sciences, India, for providing the laboratory facilities to carry out the characterization studies.

5. References

1. M. Akkas, S. Islak, Microstructure, Wear and Corrosion Properties of NiB-TiC Composite Materials Produced By Powder Metallurgy Method, Science of Sintering. 51 (2019) 327-338.
2. S. Islak, H. Celik, Effect of Sintering Temperature and Boron Carbide Content on the Wear Behavior of Hot Pressed Diamond Cutting Segments, Science of Sintering. 47 (2015) 131-143.
3. K. Oikawa, L. Wulff, T. Iijima, F. Gejima, T. Ohmori, A. Fujita, K. Fukamichi, R. Kainuma, K. Ishida, Promising Ferromagnetic Ni–Co–Al Shape memory alloy System”, Applied Physics Letters. 79 (2001) 3290-3292.
4. R. Kainuma, M. Ise, C. C. Jia, H. Ohtani, K. Ishida, Phase equilibria and microstructural control in the. Ni-Co-Al system, Intermetallics. 4 (1996) 151-158.
5. Y. Murakami, D. Shindo, K. Oikawa, R. Kainuma, K. Ishida, Magnetic domain structures in Co-Ni-Al shape memory alloys studied by Lorentz microscopy and electron holography, Acta Materialia. 50 (2002) 2173-2184.
6. Yu. I. Chumlyakov, I. V. Kiryeva, E. Yu. Panchenko, E. E. Timofeeva, Z. V. Pobedennaya, S. V. Chusov, I. Karaman, H. Maier, E. Cesari, V. A. Kirillov, Superelasticity, high temperature in CoNiGa, CoNiAl, NiFeGa and single crystals of TiNi, Russian Physics Journal. 51 (2008) 1016-1036 (in Persia).
7. M. Ellner, S. Kek, B. Predel, To the existence of a phase Co_{3}Al of the Cu_{3}Au structure type, Journal of Alloys and Compounds. 189 (1992) 245-248.
8. K. Ullako, J. K. Huang, V. V. Kokorin, R. C. O’Handley, Magnetically controlled shape memory effect in Ni_{2}MnGa intermetallics, Scripta Materialia. 36 (1997) 1133-1138.
9. K. Oikawa, T. Omori, T. Sutou, R. Kainuma, K. Ishida, Development of the Co-Ni-Al ferromagnetic shape memory alloys, Journal of Physics IV France. 112 (2003) 1017-1020.
10. Y. Tanaka, T. Oikawa, Y. Sutou, T. Omori, R. Kainuma, K. Ishida, Martensitic transition and superelasticity of Co-Ni-Al ferromagnetic shape memory alloys with $\beta + \gamma$ two-phase structure, Materials Science and Engineering: A. 438–440 (2006) 1054-1060.

11. B. Bartova, D. Schryvers, Z. Yang, S. Ignacova, P. Sittner, Microstructure and precipitates in as-cast C0$_{38}$Ni$_{13}$Al$_{29}$ shape memory alloy, Scripta Materialia. 57 (2007) 37-40.

12. Wilson, A. Stephen, New materials for micro-scale sensors and actuators. An engineering review, Materials Science and Engineering R. 56 (2007) 1-129.

13. Ailian Liu1, Jiawen Xu1, Li Gao, Bingyu Qian, Effect of Y Addition on Wear Property of Ni-Mn-Ga Shape Memory Alloys, Applied Mechanics and Materials. 513-517 (2014) 517-520.

14. K. John Joshua, S.J. Vijay and D. Philip Selvaraj, Effect of Nano TiO$_2$ Particles on Microhardness and Microstructural Behaviour of AA7068 Metal Matrix Composites, Ceramics International, 44 Issue: 17 (2018) 20774-20781.

15. W. Maziarz, J. Dutkiewicz, L. Rogal, J. Grzonka, E. Cesari, Microstructure of ball milled and compacted Co-Ni-Al alloys from the $\beta$ range, Journal of Microscopy. 236 (2009) 143-148.

16. G. Johnsy Arputhavalli, S. Agilan, P. Saravanan, Influence of sintering temperature on microstructure, magnetic properties of vacuum sintered Co (-Zn)-Ni-Al alloys, Materials Letters. 233 (2018) 177-180.

17. G. Johnsy Arputhavalli, S. Agilan, M. Dinesh, S.J. Vijay, Roy Johnson, Comparative study of conventionally sintered Co-Ni-Al alloy with spark plasma sintered alloy, Science of Sintering. 50 (2018) 337-345.

18. H. Hosoda, K. Wakashima, T. Sugimoto, S. Miyazaki, Hardness and aging of Ni$_2$MnGa ferromagnetic shape memory alloys, Materials Transactions. 43 (2002) 852-855.

19. M. Villa, K. Pantleon, M.A. Somers, Evolution of compressive strains in retained austenite during sub-zero Celsius martensite formation and tempering, Acta Materialia. 65 (2014) 383-392.

20. Y. Lina, Y. Liu, Wear behavior of Austenitic NiTi shape memory alloy, Shape Memory and Superelasticity. 1 (2015) 58-68.

Сажетак: У овом раду испитивани су отпорност на хабање и микро-чврстоћу Co$_{38}$Ni$_{13}$Al$_{27}$ и Co$_{35}$Zn$_{10}$Ni$_{32}$Al$_{23}$ феромагнетских легура. Узорци су припремљени методом металургије праха и синтеровањем у вакууму. Основни циљ је био да се припреме легура које ће имати високу отпорност на хабање и изванредну микро-чврстоћу погодне за легуру са одрживим меморијским обликом. Тест тврдоће је показао да је тврдоћа највећа за узорак синтерован на 673 K и да равномерно опада са снижењем температуре синтеровања. Такође је показано да одатак цинка у легуру повећава тврдоћу. Максимална вредност микро-тврдоће је 126 HV за узорак Co$_{38}$Ni$_{13}$Al$_{27}$ синтерован на 673 K, 8 сати услед минимума порозности.

Кључне речи: кобалт никл алуминијумска легура; металургија праха; синтеровање у вакууму; механичка својства.