Machining of Shape Memory Alloys through Different Non Conventional Machining Process

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***Abstract* – Shape Memory Alloys are highly advanced materials which have the capability to restore themselves with change in pressure, temperature etc. They have variety of applications in aerospace, defense, biomedical etc. In case of shape memory alloys, nitinol is most commonly used. The objective of this sort of research is to identify the type of machining required as wire EDM, laser cutting, EDM etc and also to study the effect of various critical parameters as voltage, pulse off time, pulse on time,current on material removal rate, electrode wear rate, surface roughness etc. Thus different machining are used so as to maintain surface integrity in case of shape memory alloy.**

***Keywords* — Shape memory alloys, kerf width, superelasticity, nitinol, material removal rate.**

I. INTRODUCTION

Shape memory alloys are those materials which have the ability to regain its shape after severe deformation. They display a special property known as super elasticity **[1]**.There are different types of shape memory alloys as Copper based shape memory alloy (CuAlNi,CuSn),Nickel Titanium based alloys (NiTiCu,NiTiFe,NiTi, NiTiPd,NiTiCo), Iron based alloys (FeMnSi).But mostly NiTi alloys are used **[2].**SMAs are used in different application of aerospace, medical industry, mobile phone antennas etc **[3].**They have several properties as high wear resistance, high biocompatibility, high strength to weight ratio, high tensile strength, super elasticity, low density**[4].**Conventional machining of shape memory alloys are difficult so non-conventional machining as electro discharge machining, laser cutting, wire EDM are used for machining of them **[5].**There are different types of techniques used in manufacturing of NiTi based shape memory alloys as shown in Figure 1 :

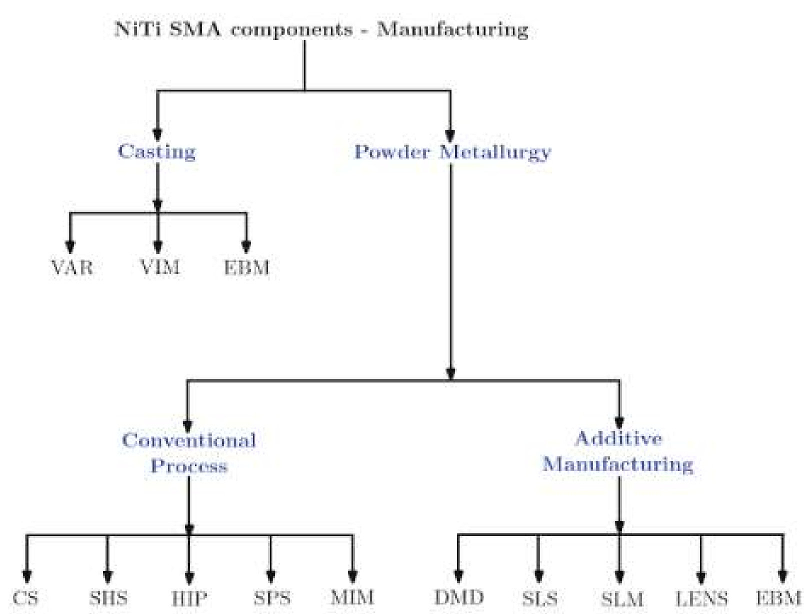

Figure 1. Manufacturing techniques employed for NiTi based Shape Memory Alloys**[6]**

Figure1. VAR - Vacuum Arc Remelting
VIM - Vacuum Induction Melting
EBM - Electron Beam Machining
CS - Conventional Sintering
SHS - Self propagating high temperature synthesis
HIP – Hot Isostatic Pressing
SPS - Spark Plasma Sintering
MIM – Metal Injection Moulding
DMD - Direct Metal Deposition
SLS - Selective Laser Sintering
LENS – Laser Engineered Net Shaping

Shape memory alloys have two stable phases with different crystallography. The low temperature phase is called martensite phase and the high temperature phase is called austenite .Reversible transformation from austenite to martensite are closely related to functional properties of shape memory alloys. SMAs also show high damping capacity in martensitic state and in two phase condition also **[7].**

II. LITERATURE REVIEW

There are different types of shape memory alloy as among all nickel based shape memory alloy is difficult to machine with conventional techniques of machining. So different non-conventional machining techniques are used to improve surface finish of the desired products **[8]**.

2.1 Studies on non-conventional machining of SMAs

Weinert et al. [9] investigated that different process parameter like feed rate,cutting speed etc are to be used to determine the machinability of NiTi shape memory alloys.Drilling NiTi based SMA gives good results. And micro hardness could be increased by drilling and deep hole drilling.

Lee et al. [10] worked on the difference between measured material removal rate (MRR) and simulated material removal rate (MRR).When the duty factor of pulsed power source increases, then measured MRR approaches to that of simulated MRR. And also due to increase in applied current the quality of machined surface decreases .It is concludedthat the change in duty factor affects the electrochemical reaction. When the gap between tool electrode and that of machined surface increases then rate of electrochemical reaction decreases.

Frotscher et al. [11] discussed the unique technique for cutting thin sheets of NiTi based SMAs.They used two process on their experiment i.e. micromilling and water jet machining .And found that water jet machining is quite good in terms of operational cost, cutting time etc. But for the medical application where high accuracy and precision is required, there electropolishing is to be done. Thus after their experiments, they found surface with good accuracy but burr formation is not completely removed.

Sang Lee et al. [12] worked on various machining condition so as to find stable electrochemical polishing process for nitinol based shape memory alloys. They used acid and neutral electrolyte in electrochemical polishing process but after performing an experiment they found that acid electrolyte is suitable for slow and precision machining whereas neutral electrolyte does not give precision machining.Even while using neutral electrolyte,generation of holes on the surface of nitinol takes place.On application of high current, surface roughness would be improved.Under the most prominent condition,nitinol surface was polishedup to surface roughness of 0.37 μmand acid electrolyte was used.Applied current of 18A and the pulse on/off time were 800μs and 200 μs. And finally surface roughness of 0.31 μm was obtained.

Daneshmandet al. [13] focused on the effect of various input parameters like pulse current, voltage, pulse off time, pulse on time on different parameters like tool wear rate, material removal rate, surface roughness, electrode wear etc while machining NiTi based shape memory alloy. They found that mostly pulse on time and pulse current affects material removal rate. As surface roughness increases with increase in pulse current and tool wear. It increases up to a certain point with increase in pulse on time up to 50 μs. It is also seen that tool wear and material removal rate decreases with increase in pulse off time. For maximum material removal rate deionized water, Cu tools and highest values of pulse on time and pulse current were chosen. As increment in voltage also causes increase in tool wear rate and material removal rate but the enlargement of surface pits reduces the characteristics of machined surface.

Manjaiah et al. [14] used taguchi approach to determine optimal values of servo voltage, pulse off time,pulse duration, flushing pressure etc so as to maximize material removal rate and reduce surface roughness. And they found that pulse duration is most prominent parameter accompanied with pulse off time and flushing pressure. Formation of peaks were identified through 3D surface morphology. And scanning electron microscope was used to see the agglomerated globules of the debris. After a larger pulse off time, white layer formation on machined surface takes place.High surface hardness was also observed due to the formation of alloy compounds.

Liu et al. [15] investigated the surface integrity with the help of scanning electron microscopy, stylus profiler, and found the surface contour as "coral reef" at the main cut (MC) and first trim cut (TC) .But isotropic surface is generated at the finish trim cut while doing wire EDM of nitinol.It is also seen that micro cracks are generated because of high tensile residual stress in case of de-ionized water rather than CH-coil. Thus at main cut, due to high discharge energy, discontinuous form of thick white layer is formed that could be reduced at finish trim cut.

Huang et al. [16] analyzed that electrode wear rate, surface roughness and material removal rate decreases in case of $Ti_{50}Ni_{49.5}Cr_{0.5}$ shape memory alloysin comparison to $Ti_{50}Ni_{50}$shape memory alloy. As by adding chromium to $Ti_{50}Ni_{50}$ shape memory alloy, decreases its transformation temperature. This enhances its use in biomedical applications.It is also found that surface roughness is improved after EDM .The formation of recast layer containing CrN and TiC provide good corrosion and wear resistance.Thus it also helps to restrict metal substrate to get in contact with body fluid during implantation of shape memory alloy in the human body.

Manjaiah et al.[17] investigated different characteristics of wire electro discharge machining as material removal rate, recast layer thickness, surface roughness etc. of $Ti_{50}Ni_{50-x}Cu_x$

shape memory alloy .As they found that as pulse on time increases, surface roughness and material removal rate also increases,but as pulse off time and servo voltage increases,surface roughness and material removal rate (MRR) decreases.As $Ti_{50}Ni_{30}Cu_{20}$ shape memory alloy shows higher MRR and surface roughness because of increase in thermal conductivity and melting temperature.The formation of recast layer thickness also increases with increased pulse on time. As 49.4% is the percentage increase in hardness for lower pulse on time and 59% for higher pulse on time.

Jaware et al.[18]discussed that EDM and WEDM are mostly used to machine workpieces having complex shapes.As discharge current increases, MRR also increases but it also causes the degradation of surface roughness of workpiece. But when duration of pulse increases with increase in discharge energy,then surface roughness increases. The thickness of recast layer is controlled by optimum pulse on time and other process parameter.

Roy et al. [19] explored that while performing wire electro-discharge machining of $Ti_{50}Ni_{40}Cu_{10}$, higher material removal rate is found as compared to $Ti_{40}Ni_{50}Cu_{10}$.As while kerf width is taken into consideration then servo voltage which is followed by pulse ion time is proved to be influential.

James et al. [20] found that nitinol and lead zirconate titanate can be easily machined with abrasive water jet micromachining (AWJMM) and submerged abrasive water jet micro machining process (SAWJMM). In case of SAWJMM, some circular cavities are produced that have smaller diameter in comparison to AWJMM. But those cavities does not show any cracking. They found that as stand-off distance increases, taper angle and size of cavity also increases but MRR decreases. As a result MRR is lesser in case of SAWJMM in comparison to AWJMM.

Sharma et al. [21] concluded that pulse on time plays an important role while wire spark erosion machining of $Ni_{55.8}Ti$ shape memory alloy.They found that surface roughness increases with increase in pulse on time and servo voltage and decrease in pulse off time.It is seen that surface deterioration takes place mainly due to generation of intense heat and resolidification of molten metal.It is also seen that high discharge energy causes the formation of surface defects,cracks,globules and deposition of wire material on surface of workpiece.These things were analyzed through XRD and EDS. Optimization of wire spark erosion machining (WSEM) helps to control the level of discharge energy and also reduce the surface irregularities.And maximum surface roughness of 7.78 μmand the thick ness of recast layer 4-6μmwas found during wire spark erosion machining (WESM) of $Ni_{55.8}Ti$.

III. CONCLUSION

The following conclusions are drawn after reviewing the above mentioned literature:

- For machining shape memory alloys, generally non-conventional techniques like wire EDM, EDM etc are employed so as to use them in variety of applications.
- Water jet machining followed by electropolishing is also used, so to make the use of shape memory alloys in medical applications.
- In case of NiTi shape memory alloys,material removal rate is greatly affected by pulse current and pulse on time.

REFERENCES

[1]. **T W Dureig, K N Melton, D Stockel, C M Wayman,** " Engineering Aspects of Shape Memory Alloys", ISBN 0-750-61009-3,Butterworth-Heinemann Ltd.,pp. 3-4,1990

[2]. **Kush Mehta, Kapil Gupta**, "Fabrication and Processing of Shape Memory Alloys", ISBN 978-3-319-99307-2, pp. 6-7, 2019

[3]. **Arun D I, Chakravarthy P, Arockia Kumar R, Santosh B**, " Shape Memory Materials, ISBN 978-0-8153-5969-2,Taylor and Francis Gp., pp. 20-21, 2018

[4]. **NewnhamR. & Ruschaun, G.R.,** "Electrochemical properties of smart materials", Journal of Intelligent Material System and structure, pp. 288-293,1993

[5]. **Donald R. Askeland, Pradeep P.Phule,** "The Science And Engineering of Materials", ISBN 0-534-55396-6,Cengage Learning, 5th Edition, pp 612-625, 2006

[6]. **Ashwin Rao, A.R.Srinivasa, J.N.Reddy**, "Design of Shape Memory Alloy (SMA) Actuators", Springer Briefs in Applied Sciences and Technology, pp 44-46, 2015

[7]. **Leonardo Lecce & Antonio Concilio**, "Shape Memory Alloy Engineering", ISBN 978-0-08-099920-3,Elsevier Ltd.,pp. 31-35,2015

[8]. **J.F. Liu, Y.B. Guo, T.M. Butler, M.L. Weaver,** "Crystallography, compositions, and properties of white layer by wire electrical discharge machining of nitinol shape memory alloy", Materials and Design, vol. 109, pp. 1-9, 2016

[9]. **K.Weinert, V.Petzoldt,** "Machining of NiTi based shape memory alloys, Materials Science and Engineering 378-180–184, 2003

[10]. **Eun-Sang Lee,Tae-Hee Shin, Baek-Kyoum Kim and Seung-Yub Baek**, "Investigation of Short Pulse Electrochemical Machining for groove process on NiTi shape memory alloy", International Journal of Precision Engineering & Manufacturing, vol.11, pp.113-118,2010

[11]. **M. Frotscher, F. Kahleyss, T. Simon, D. Biermann, G. Eggeler,**"Achieving Small Structures in Thin NiTi Sheets for Medical Applications with Water Jet and Micro Machining: A Comparison", JMEPEG 20:776–782,2011

[12]. **Eun Sang Lee, Tae Hee Shin,** "An evaluation of the machinability of nitinol shape memory alloy by electrochemical polishing",Journal of Mechanical Science and Technology 25-4-963-969,2011

[13]. **Saeed Daneshmand, Ehsan Farahmand Kahrizi, Esmail Abedi, M. Mir Abdolhosseini,** "Influence of Machining Parameters on Electro Discharge Machining of NiTi Shape Memory Alloys", Int. J. Electrochemical. Sci., 8 -3095 – 3104, 2013

[14]. **M.Manjaiah, S.Narendranath, S.Basavarajappa, V.N. Gaitonde,** "Wire electric discharge machining characteristics of titanium nickel shape memory alloy",Trans. Nonferrous Met. Soc. China 24-3201-3209, 2014

[15]. **J.F.Liu,Y.B.Guo,** "Process Capability of Wire EDM of NiTi Shape Memory Alloy at main cut and trim cut codes", Vol 1, Procedia Manufacturing, pp. 904-914,2015

[16]. **Tyau-Song Huang, Shy-Feng Hsieh, Sung-Long Chen, Ming-Hong Lin, Shih-Fu Ou, Wei-Tse Chang, "**Surface modification of TiNi-based shape memory alloys by dry electrical discharge

machining", Journal of Materials Processing Technology,279-284,2015

[17]. **M Manjaiah, S Narendranath, S Basavarajappa,V.N. Gaitonde,** "Investigation on material removal rate, surface and subsurface characteristics in wire electro discharge machining of $Ti_{50}Ni_{50-x}$ Cu_x shape memory alloy", J Materials: Design and Applications, 2015

[18]. **Dr.V.B.Jaware, A.M.Takale,** "Review on EDM and Wire-EDM machining of TiNi Shape Memory Alloys",Vol. 3, Issue 1,2015

[19]. **Abhinaba Roy, Narendranath S.,** "Study of Wire Electro Discharge Machining Accuracy of TiNiCu Shape Memory Alloys through Kerf Analysis", Proceedings of 10th International Conference on Precision, Meso, Micro and Nano Engineering,2017

[20]. **Sagil James, Anurag Mahajan,** "Experimental Study of Machining of Smart Materials using Submerged Abrasive Water jet Micromachining Process", Proceedings of the ASME 13th InternationalManufacturing Science and Engineering Conference,2018

[21]. **Neeraj Sharma, Kapil Gupta, Joao Paulo Davim,** "On wire spark erosion machining induced surface integrity of $Ni_{55.8}Ti$ shape memory alloys", Archives of Civil and Mechanical Engineering, Vol.19,Issue 3,2019