EXPERIMENTAL INVESTIGATIONS ON MACHINING CHARACTERISTICS IN WIRE-EDM OF TiNi SHAPE MEMORY ALLOY

Author - Dr. Adik M Takale, Mr. G. V. Pujari
Department - Mechanical Engineering
E-mail Id –adik1617@sitcoe.org.in, pujari.ganesh@sitcoe.org.in

ABSTRACT

Ti-Ni alloys are a vital class of shape memory alloys (SMAs). Lately, materials, for example, Ti-Ni based SMAs and different SMAs are normally utilized in therapeutic and a few building uses. Therapeutic application incorporate eye glass frame, careful stent, orthodontic arch wire, dynamic catheter and modern building application is practical gadgets, for example, latches, fixing and coupling, aviation actuators, sensors, radio wires and fuel injector.

Due to its excellent quality at lower to direct temperatures, shape memory effect (SME), excellent wear resistance, considerable consumption resistance, lightweight, high biocompatibility, etc., Ti-Ni combinations are frequently used. When Ti and Ni are combined, the microstructure often goes through a martensitic stage at lower temperature and an austenitic stage at higher temperature.

Ti-Ni shape memory alloy (SMA) machinability research has become a crucial component of the machining field. Because of their high synthetic reactivity and limited heat conductivity, titanium compounds are incredibly difficult to machine. Efficiency as well as surface integrity is noted as crucial steps in process of cutting. Use of a high machining velocity can result in increased profitability. Due to increased device wear (fast chipping to the bleeding edge, plastic twisting of front line), better surface hardness, significant microstructure changes, bad surface finish, typical cutting of these material at higher machining speeds is particularly challenging. They can then be effectively processed using non-traditional machining techniques including Laser Machining, Electro Discharge Machining (EDM), Wire-Electro Discharge Machining (WEDM).

WEDM uses can likewise be found in therapeutic, optical, dental and Rand D regions. Other famous use for WEDM is cutting of extrusion dies.

Integrated shape of Ti-Ni SMAs is hard to machine by conventional machining, in that case WEDM is preferred also the WEDM very precise, accurate and irregular intricate shape can be produced.

In the macro-WEDM of Ti49.5 Ni50.6 (Atomic percentage) SMA, the impact of changing five procedure variables, including pulse on time (Ton), pulse off time (Toff), spark gap set voltage (SV), wire feed (WF), and wire tension (WT), on the material removal rate (MRR), kerf width (KW), surface roughness (SR), as well as dimension variation (DD), has been examined. In this work, L18orthogonal array (OA) in view of Taguchi technique has been utilized to direct a progression of trials and statically assess the exploratory information by the utilization of the strategy for Analysis of Variance (ANOVA).

Ti-Ni SMA is taken into consideration for the current work because to its intriguing features and

biocompatibility. To assess the effects of process factors, signal to noise (S/N) ratio chart is dissected. With a contribution of 35.69% for MRR and 59.02% for SR, Ton was shown to be the most important element. At a 95% confidence level, the SV contributes 47.35% and 30.03%, accordingly, to KW and DD. Grey relational analysis (GRA) has been used in a multi-reaction enhancement to select the best selection of procedure variables. It has been demonstrated to using GRA, ideal machining variable configuration, A2B2C3D2E2, i.e. Maximum MRR and minimal SR, KW, and DD have been recorded for (Ton of 115 machine unit, Toff of 40 machine unit, SV of 90 V, WF of 6 m/min and WT of 6 machine unit). Checked for biocompatibility using Young's modulus. Images taken using scanning electron microscopes (SEM) are confirm results that provide superior surface quality. A particular amount of material has been deposited on the machined surface, according to Energy Dispersive Spectroscopy (EDS) measurements. It has been found that annealing is the most suitable heating procedure for recovering SME from macro-WEDM tests.

Micro-WEDM is non-conventional process utilized to make 3D, intricate, smaller scale includes on hard to-cut machine materials. Then again, low machining proficiency and poor surface quality are confining its utilization in the exactness producing segment. Along these lines, in this work, an endeavor has been made to enhance the machining effectiveness of micro- WEDM.

The effect of machining parameters viz. gap voltage (GV), capacitance (C), WF and WT on response parameter MRR, SR, KW and DD of micro-WEDM was studied on Ti49.4 Ni50.6 SMA. Nine analyses have been performed dependent on the Taguchi design of experiment (DOE).

GRA strategy is connected to decide an ideal arrangement of process parameters for micro-WEDM. It is seen that upgraded set of parameters A3B3C3D1, i.e. GV of 140 V, C of 0.4 µF, WF of 30 µm/sec and WT of 30%, controlled by utilizing GRA offers most extreme MRR and least SR, KW and DD. From ANOVA, it is found that procedure variable C is important variable for multi-reaction streamlining with rate commitment of 77.91%. Likewise, SEM picture is taken to affirm outcomes offer good surface finish. EDS examination of the machined surface has appeared certain measure of an deposition of material on the machined surface.

Ti49.4 Ni50.6 SMA is unique class of smart material due to its characteristics. SMA is used in a wide assortment of utilization over a wide scope of fields including an orthopedic implant. It assumes an imperative job in construction of novel orthopedic implant due to it lower Young's modulus than other biomedical insert material, strong mechanical strength, superior corrosion resistance, special SME characteristic. Although WEDM may achieve great dimensional accuracy, its heated nature raises serious questions about the surface stability for applications involving Ti-Ni materials that require biocompatibility. Investigating surface morphology and safe, non-hazardous surfaces for the human body is therefore important. Ti-Ni WEDM can therefore be applied. In order to achieve high biocompatibility of machined surface, a WEDM improved process has been used to manufacture the Ti-Ni implants, and various execution traits, such as SR, surface topography, metallurgical change, recast layer, residual stresses, micro-hardness, and recovery of shape capacity of machined part has been assessed.

For the validated experiment of macro-WEDM with an increase in wire feed, a minimal surface roughness via regularity, appropriate surface integrity variables, such as less material deposition, least recast layers of its thickness, consentaneous the quantity of surface hardness, and fewer factors impacting subsurface residual stresses were established. The two most often used materials as biomedical orthopedic restorative devices are Ti49.4Ni50.6 SMA and AISI SS316L. Surface characteristics of biomedical inserts play a significant role in their biocompatibility and therapeutic value. Ti-Ni SMAs and SS-316L depends inserts show that an orthopedic implant was built with a movable centerpiece. Macro-WEDM was used to make implants made of SS316L and Ti-Ni SMAs. Ti49.4Ni50.6 and SS316L were subjected to macro-WEDM, and various execution parameters, including as topography, material migration, recast layer, micro-hardness, and residual stresses machined components, were assessed. For Ti49.4Ni50.6 SMA, the smooth surface with consistency adequate surface integrity variables such as minimal recast layer thickness, consistent amount of surface hardness, less impacting subsurface residual stress—was discovered. Ti49.4 Ni50.6 SMA has a lower bending stiffness than SS316L because its Young's modulus is lower (55630 MPa) than that of SS316L (145450 MPa).

1. INTRODUCTION

In this chapter, the properties and the processes of machining of SMAs are discussed. A brief review of non-conventional machining of SMAs is presented. The basic principles of macro-WEDM and micro-WEDM processes are elucidated. Also, the research objectives, the scope of research work and the outline of the examination work are presented.

I. Shape Memory Alloy

An SMA is a combination that "recollects" its unique shape and not long after miss happening come back to it pre-disfigured shape when heated. SMA is a low-weight, strong state option in contrast that traditional actuator, such as, pressure driven, pneumatic and engine operated framework. SMAs have applications in mechanical autonomy and biomedical ventures.

The two primary kinds of SMAs are Cu Al Ni and Ti-Ni alloys. SMAs can likewise be made by blending Zn, Cu, Au and Fe in right extents. The Fe based, Cu-based SMAs, like, Fe-Mn-Si, Cu-Zn-Al and Cu-Al-Ni industrially suitable and cheap compared Ti-Ni. In any case, Ti-Ni based SMAs have been favored for more therapeutic and designing application because of its strength, superior thermo-mechanic, and practicability characteristics.

II. One-way vs. two-way shape memory

Ho et al. (2004) [1] observed that SMAs have various shape memory effects (SMEs). Two basic impacts is one-way and two-way shape memory. result of impacts appears in Figure 1.

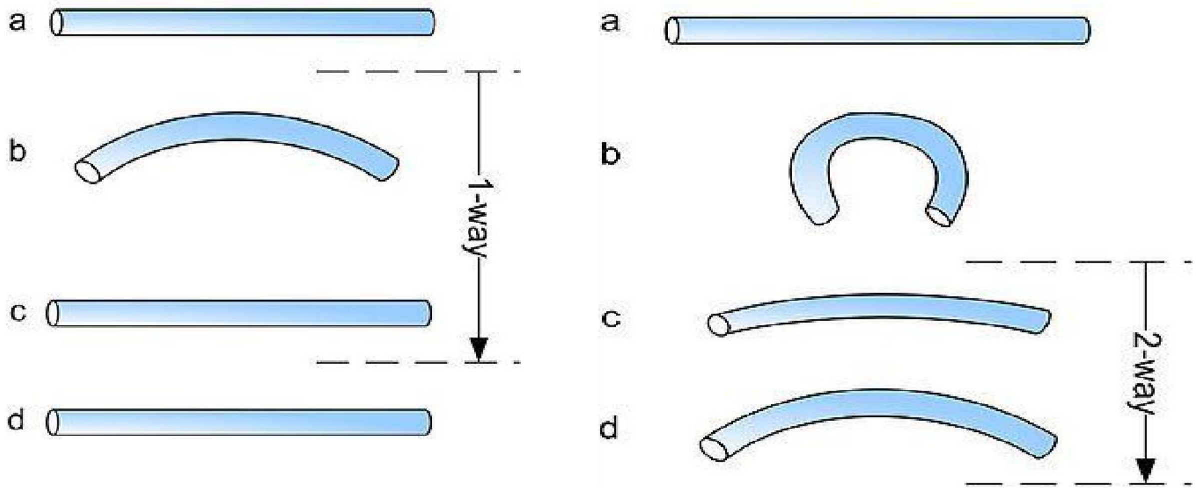


Fig 1 The strategies are fundamentally the same as beginning from martensite (a), including a reversible twisting for restricted impact serious distortion with irreversible sum for two-way (b), warming example (c) and cooling it once more (d).

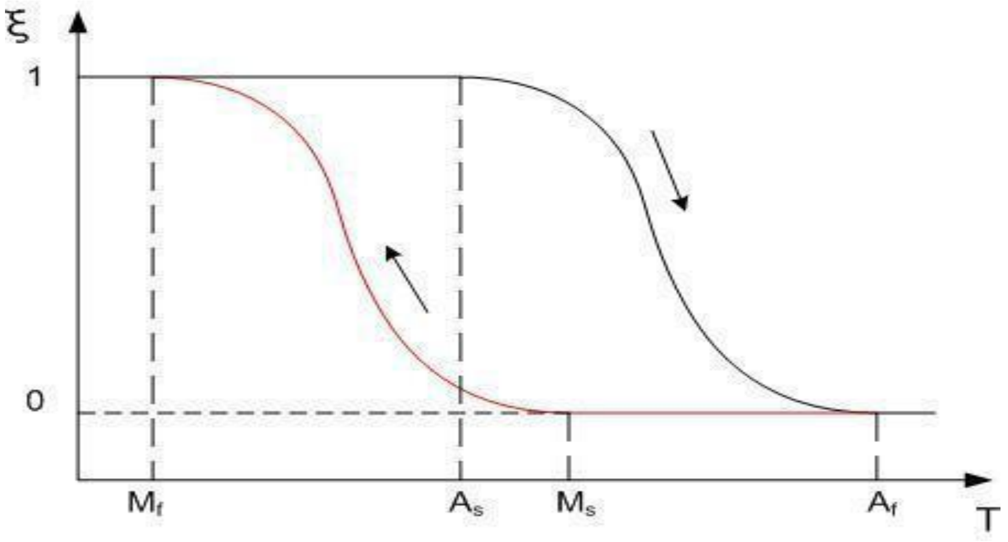


Fig 2: Effect of Shape Memory Alloy.

III. One-way SME

At the point when an SMA is at cool condition (beneath A_s), metal is twisted or extended and shall take it shapes until warmed over changing temp. After warming, shape alters to it unique. At point when the metal cooled, it shall stay in hot shape, till disfigured once more. On warming, change begins at A_s and is finished at A_f (normally 2 to 20 °C or more blazing, contingent upon the amalgam or stacking condition). As is controlled by compound kind as well as organization and can fluctuate between −150 °C and 200 °

IV. Two-way SME

The two-way SME is the impact that the material recollects two distinct shapes: one at low temperatures and one at the high-temperature shape. A material that demonstrates an SME amid both warming and cooling is called two-way shape memory. This can likewise be gotten without the use of an outside power (natural two-way impact). The cause the material carries on so contrastingly in these circumstances lies in preparing. Preparing suggests that a shape memory can "learn" to carry on with a particular goal in mind. Under ordinary conditions, an SMA "recollects" its low-temperature shape, yet after warming to recuperate the high-temperature shape, quickly low-temperature shape. Be that as it may, it very well may be "prepared" to "recall" to abandon a few notices of the distorted low-temperature condition in the high-temperature stages. There are a few different ways of doing this. A formed, prepared question warmed past a specific point will lose the two-way memory impact.

V. Manufacturing processes

Manufacturing procedures can be extensively isolated into two gatherings and they are essential manufacturing procedures and manufacturing assembling forms. The previous one gives fundamental shape and size to the material according to the designer’s necessity. Casting, shaping, powder metallurgy are such procedures to give some examples. Auxiliary manufacturing forms furnish the last shape and size with more tightly control of measurement, surface qualities and so on. Material expulsion forms are essentially secondary manufacturing forms.

VI. Manufacturing methods of SMA

Nitinol (Nickel-Titanium Naval Ordnance Laboratory) is exceedingly hard to make because of the astoundingly tight compositional control required and the colossal reactivity of titanium. Each molecule of titanium that joins with oxygen or carbon is an atom that is victimized from the Ti-Ni grid, in this manner moving the piece and making the changing temperature that a lot colder. There are two essential dissolving strategies utilized today are –

- **Vacuum Arc Remelting (VAR)** –

This procedure was completed by arresting an electrical arc between a tungsten terminal and the crude material. Liquefying is brought through an electric spark in argon condition so no carbon is presented amid softening.

- **Vacuum Induction Melting (VIM) –**

VIM process was completed by utilizing substituting attractive fields to warm the crude materials in a cauldron (for the most part graphite). This is likewise arranged in a high vacuum, yet carbon is presented amid the procedure.

While the two strategies have favorable circumstances, there are no substantive information appearing material from one process is superior to the next.

Material expulsion forms indeed can be partitioned into chiefly two gatherings and they are "Conventional Machining Processes" and "Non-Conventional Manufacturing Processes". Instances of conventional machining forms are turning, boring, milling, shaping, broaching, slotting, grinding and so forth. Thus, Ultrasonic Machining (USM), Water-Jet-Machining (WJM), Laser-Machining, WEDM and EDM are a portion of the Non-Conventional Machining Processes.

VII. Conventional machining of SMAs

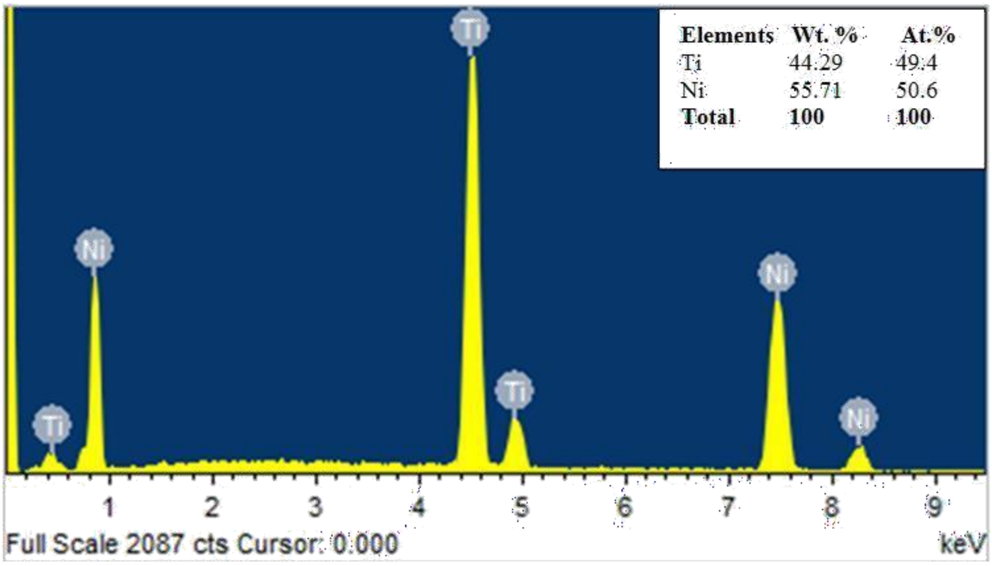
Machining of SMAs are generally a critical, necessary part in creation as segments to use in engineering application. At the point when Ti-Ni SMAs are considered, Ti reactivity towards cutting tool, less heat transfer rate, great quality to hoisted temperature and less elastic modulus results to expanded temperature at apparatus chip interface, component contortions, quick tool wear. Ni based alloys, super compounds like Ti combinations likewise have good quality and is viewed as difficult to machine. Also, because of their austenitic grid nickel super alloys solidify quickly amid machining and will, in general, deliver a consistent chip which is hard to control amid machining. The previously mentioned impacts lead to quickened flank wear, cratering and scoring, contingent upon the tool material and the cutting conditions connected. (Refer to Figure 3).

VIII. EXPERIMENTAL RESULTS AND ANALYSIS FOR MACRO-WEDM

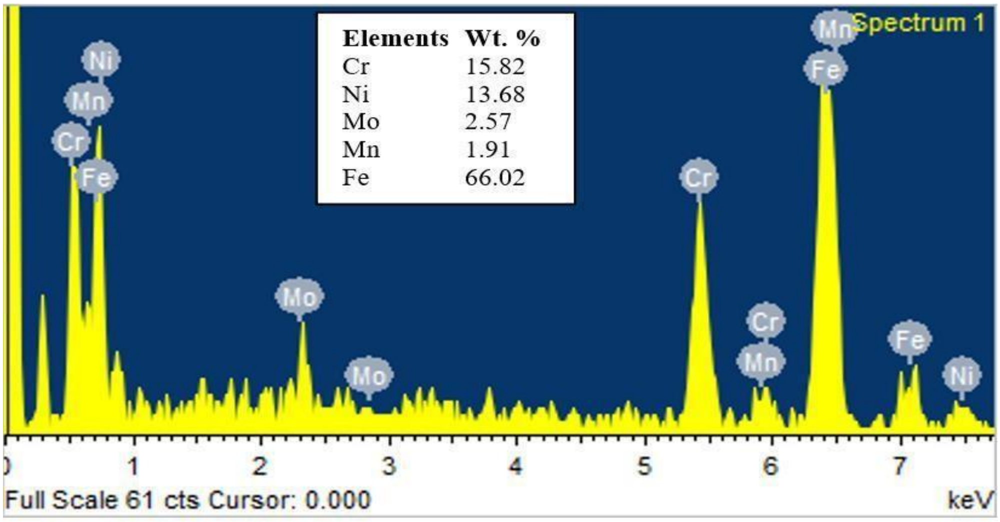
The present section gives the use of the Taguchi trial plan strategy. To study effect of process factors on the yield parameters, like MRR, SR, KW, and DD, the strategy of concluding studies was selected and the trials were lead using macro-WEDM. The test findings are discussed. Using GRA, procedure variables are multi-objectively adjusted. Also, Salon it is thermal modeling of the macro- WEDM is presented. The study on the surface integrity of the macro-WEDM surfaces is taken up.

Fig 3: Pictorial view of macro-WEDM machine tool.

For every experiment run of L18 OA of Table 1, the predefined input variable selections were set and specimens of Ti-Ni SMA was machined utilizing zinc coated brass wire electrode. So as to maintain a strategic distance from the blunder crawling into the framework, the preliminaries were randomized. Execution attributes, for example, MRR, SR, KW and DD were evaluated for each of the experimental runs of OA.



Elements	Wt. %	At.%
Ti	44.29	49.4
Ni	55.71	50.6
Total	**100**	**100**



Elements	Wt. %
Cr	15.82
Ni	13.68
Mo	2.57
Mn	1.91
Fe	66.02

Fig 4: Pictorial view of a macro-WEDM machine tool

Table 1 Controllable parameters and their levels

variables	Code	Level1	Level2	Level3
Pulse on Time(Machine Unit)	T_{on}	105	115	--
Pulse off Time(Machine Unit)	T_{off}	20	40	60
Spark gap set Voltage(V)	SV	30	60	90
Wire Feed (m/min)	WF	3	6	12
Wire Tension(Machine Unit)	WT	3	6	12

Table 2 Experimental design using an L18 orthogonal array

Experiment Number	Process Levels variable settings				
	Ton	Toff	SV	WF	WT
1	105	20	30	3	3
2	105	20	60	6	6
3	105	20	90	12	12
4	105	40	30	3	6
5	105	40	60	6	12
6	105	40	90	12	3
7	105	60	30	6	3
8	105	60	60	12	6
9	105	60	90	3	12
10	115	20	30	12	12
11	115	20	60	3	3
12	115	20	90	6	6
13	115	40	30	6	12
14	115	40	60	12	3
15	115	40	90	3	6

16	115	60	30	12	6
17	115	60	60	3	12
18	115	60	90	6	3

IX. Experimental Results

The trial result of MRR, SR, KW and DD are listed in Table 2. Eighteen investigations were directed utilizing Taguchi exploratory plan procedure and every trial was repeated 3 times for getting S/N ratios. Present investigation, every one of the structures, plots and examination has been completed utilizing Minitab statistical software.

Table 3 S/N ratio for MRR, SR, KW and DD

Expt. No.	Average MRR	S/N Ratio	Average SR(Ra)	S/N Ratio	Average KW	S/N Ratio	DD (%)	S/N Ratio
1	0.6268	-4.057	1.205	-1.620	0.299	10.487	0.839	1.525
2	1.2929	2.231	1.926	-5.693	0.296	10.574	0.787	2.081
3	1.2282	1.785	1.579	-3.968	0.301	10.429	0.709	2.987
4	0.6338	-3.961	1.785	-5.033	0.293	10.663	0.619	4.166
5	0.5689	-4.899	1.296	-2.252	0.292	10.692	0.774	2.225
6	0.7691	-2.280	1.149	-1.206	0.305	10.314	1.006	-0.052
7	0.1915	-14.357	0.862	1.290	0.297	10.545	0.593	4.539
8	0.1790	-14.943	1.202	-1.598	0.303	10.371	0.464	6.670
9	0.1173	-18.614	1.022	-0.189	0.309	10.201	0.541	5.336
10	3.4970	10.874	2.744	-8.768	0.310	10.173	0.529	5.531
11	1.7054	4.637	2.416	-7.662	0.317	9.979	0.787	2.081
12	2.9815	9.489	2.005	-6.042	0.309	10.201	0.800	1.938
13	2.3930	7.579	2.526	-8.049	0.302	10.400	0.671	3.466
14	4.0065	12.055	2.253	-7.055	0.304	10.343	0.658	3.635
15	1.7155	4.688	1.460	-3.287	0.317	9.979	1.096	-0.796
16	0.6419	-3.851	2.235	-6.986	0.304	10.343	0.477	6.430
17	0.5657	-4.948	1.936	-5.738	0.313	10.089	0.503	5.969
18	0.4621	-6.705	1.947	-5.787	0.324	9.789	0.929	0.640

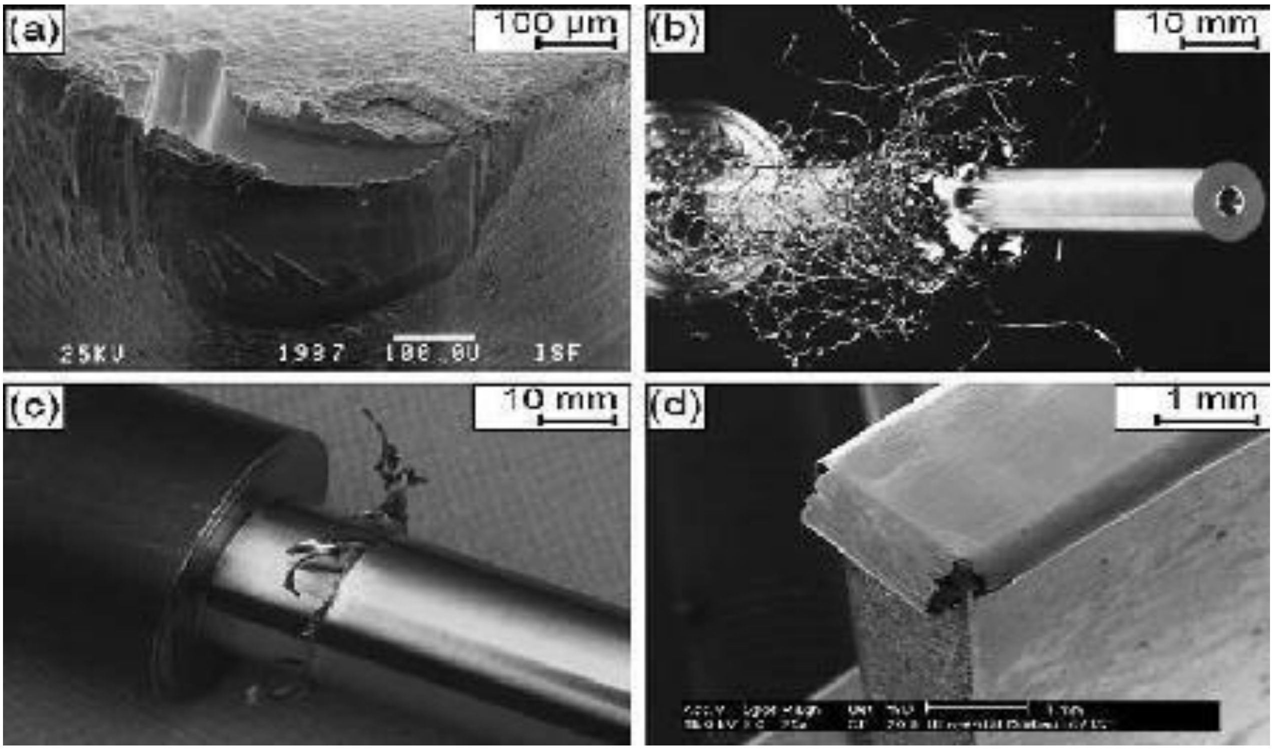


Fig. 5 Difficulties occurred during conventional machining of Ti-Ni alloy a) High tool wear b) Adverse chips c) Burr

formation after machining d) After grinding

X. Result Analysis and Discussion

WEDM test was directed utilizing parametric methodology of Taguchi's strategy. Impacts of single WEDM process variable, on chose ability attributes like MRR, SR, KW and DD have been talked about in this segment. Then again, the normal start hole gets enlarged with expanded SV prompting less power of sparks which causes a decrease in MRR. Simultaneously with increased WF, the liquid material is sprinkled around the surface by flushing pressure. The micro voids are framed on the machined surface because of the release of a huge volume of gases in the channel that spilled out from the liquid pool and thus higher MRR.

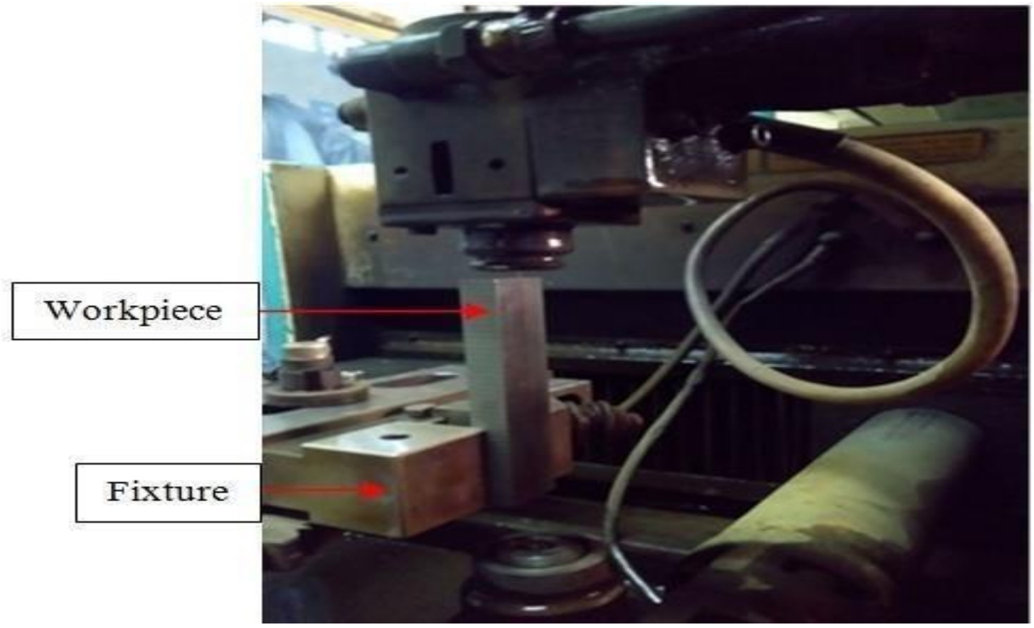


Fig 6: Experimental setup

The normal esteem and S/N proportion of the reaction attributes for every factor at various dimensions were determined from trial information. The principal impacts of procedure factors for crude information & S/N information were noted. Reaction bends (important impacts) are utilized for inspecting parametric consequences for reaction qualities. ANOVA of raw information, S/N information is completed to recognize important factors also to evaluate its consequences for the reaction qualities. Most positive qualities of process factors as far as mean reaction attributes are set up by breaking down the ANOVA Tables.

REFERENCES

1. K. H. Ho, S. T. Newman, S. Rahimifard, R. D. Allen (2004), “State of art in wire electrical discharge machining (WEDM)”, International Journal of Machine Tools and Manufacture, 44, pp. 1247-1259.
2. A. P. Markopoulos, I. S. Pressas, D. E. Manolakos (2015), “A review on the machining of nickel-titanium shape memory alloys”, Reviews on Advanced Materials Science, 42, pp. 28–35.
3. K. Weinert, V. Petzoldt (2004), “Machining of NiTi based shape memory alloys”, Materials Science A, 378, pp. 180–184.
4. M. Manjaiah, S. Narendranath, A. Javad (2014), “Optimization of wire electro- discharge machining parameters to achieve better MRR and surface finish”, Procedia Materials Science, 5, pp. 2635–2644.
5. F. Han, J. Jiang, Y. Dingwen (2007), “Influence of machining parameters on surface roughness in finish cut of WEDM”, International Journal of Advanced Manufacturing Technology, 34, pp. 538–546.
6. S. L. Chen, S. F. Hsieh, H. C. Lin, M. H. Lin, J. S. Huang (2008), “Electrical discharge machining of a NiAlFe ternary shape memory alloy”, Journal of Alloys and Compounds, 464, pp. 446-451.
7. S. Saha, M. Pachon, A. Ghoshal, M. J. Schulz (2004), “Finite element modeling and optimization to prevent wire breakage in electro-discharge machining”, Mechanics Research Communications, 31, pp. 451–463.
8. N. Tosun, C. Cogun, G. Tosun (2004), “A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method”, Journal of Materials Processing Technology, 152, pp. 316-322.
9. Y. K. Lok, T. C. Lee (1997), “Processing of advanced ceramics using the wire- cut EDM process”, Journal of Materials Processing Technology, 63, pp. 839-843.
10. G. F. Benedict (1987), “Electrical discharge machining (EDM), non-traditional manufacturing process”, Marcel Dekker, Inc, New York and Basel, pp. 231-232.