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REVIEW ON OPTIMIZATION TECHNIQUES FOR MACHINING PARAMETERS OF SHAPE MEMORY ALLOY

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ABSTRACT
Machining of Shape memory Alloys is important in specific applications for accurate dimension, tolerances, and surface finish. SMAs are extensively utilized in a wide range of applications, including MEMS devices, aircraft, actuators, biomedical, and automotive. Non-traditional methods like Electric Discharge Machining, Wire-cut Electric Discharge Machining, Water Jet Machining, Electro Chemical Machining etc. give better result than traditional machining. This paper reviews the optimization techniques applied in optimization of machining parameters in shape memory alloys. The various Optimization techniques reviewed are Taguchi Method, GRNN, Response Surface Methodology (RSM), NSGA, and HTS Algorithm. The effect of various process parameters is studied on the machining of shape memory alloy. From the extensive literature survey, it is found that Pulse on Time (Ton), Pulse off time (Toff) and Current (I) are effective parameters which shows effect on the quality of machining. Taguchi and RSM are mostly used techniques in the optimization of machining process parameters of shape memory alloy. Need to explore Artificial Intelligence based optimization techniques for optimization.

Keywords- Shape Memory Alloy, Optimization, Machining, WEDM

1. INTRODUCTION-
Shape memory alloys (SMAs) are a group of metallic alloys that can change initial shape because of applied heat or stress and return to their original shape. SMAs possessing unique properties such as super elasticity or pseudo elasticity, shape memory effect, High damping capacity, good fatigue properties and high biocompatibility. The various alloys of SMA can be obtained from nickel, titanium, zinc, copper, gold, and iron. On the basis of these alloying elements, SMAs can be broadly classified as Nickel-titanium (NiTi) SMAs, Copper (Cu) SMAs, and Iron SMAs. Special properties of SMA creates difficulties in conventional machining operation. Past studies [1] on conventional machining of SMA reported lot of tool wear, defects on surface of machined parts, and imprecise dimension. These defects create need to find alternative for conventional machining of SMA. Various non-conventional machining methods such as laser machining, Electric discharge machining (EDM), Wire EDM, Electro machining (ECM) and water jet machining (WJM) can be effectively used to machine SMAs with desired accuracy [2]. Among all the non-conventional machining processes, Wirecut EDM is widely used to perform machining of difficult to cut material. In Wirecut EDM, material is eroded from work part by the aid of number of sparks generated between the wire and workpiece. Here wire is act as anode and workpart act as cathode. Wirecut EDM is a multi-input, multi-output machining process [3]. Input parameters affect the quality of machining, hence controlling these parameters is important. Optimization of input parameters can bring significant improvements in process efficiency. In the present paper, various optimization techniques used in the process parameters optimization in the machining of shape memory alloys by various researchers are studied. The various optimization techniques namely, Taguchi method, Response surface methodology (RSM), Genetic Algorithm (GA), GRNN, Artificial Neural Network (ANN), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), NSGA, Heat Transfer Search (HTS) Algorithm etc. are used for EDM and Wirecut EDM machining of shape memory alloys.

2. PROPERTIES OF SMA:

2.1 Shape Memory Effect-

SMA exhibits shape memory effect in which original shape is memorized by the material. Exhibition of these properties takes place on the basis of diffuseness solid phase transformation. In typical operating temperature range, it has two phases: Martensite and Austenite. In Martensite phase at lower temperature material is in distorted or deformed state. In this condition material can easily change its shape. In Austenite phase material goes on phase transition and returns to its original shape. This ability to return into the original shape is because of the reversible change in crystal structure that occurs during phase transition. The transition from martensitic to austenitic is occurred because of temperature changes or other factors such as stress, magnetic field or electrical current. [4]

2.2 Pseudoelasticity-

Pseudoelasticity or superelasticity is an elastic response to an applied stress which is occurred by transformation of phase from austenitic to martensitic . In superelasticity, SMA come back to its original shape after applying mechanical loading at temperature Austenitic finish temperature (Af) and martensite start temperature (Ms) without aid of any thermal activation.[4]

2.3 Damping Properties-

SMAs demonstrate more damping capacity than other materials. In damping, mechanical energy is dissipated into heat. Energy dissipation is observed in pseudo elastic characteristic. This dissipation occurs due to production defects and dislocation movement hysteresis. Dissipated energy and total energy affected by the temperature, amplitude and excitation frequency. [4]

3. Applications of Shape Memory Alloys

Unique properties of SMA find its applications in various fields such as Automotive, Aerospace, Biomedical, Robotics etc. The combination of Nickel-Titanium is bio-compatible because of which it can be used in biomedical field to manufacture stents, eyeglass frames, implants, endodontics, medical tweezer etc. Table-2 Eren kaya et al [3] gives the variety of application areas of SMAs along with specific examples.

Table-2 Applications of SMA

Application domain	Function/part	Application examples
Automotive	Engine	Radiator, fan clutch, engine control, fuel injector, valves
	Drivetrain	Transmission control
	Wheel/brake/Suspension	Brake, absorber, tire
	Body	Lamps, wiper, sunroof, side mirror, engine hood, spoiler
	Interior	Rear view window, airbags, dashboard
Aerospace	Engine	Inlet, rotor, nozzle
	Body	Aero-structure, skin, wing, winglet, flap edge
Robotics	Biomimetic	Crawling, walking, rolling, climbing, swimming, flying
Communication	Antenna	Radio frequency slot antenna

Biomedical	Vascular	Stents, filters, arteries, vessels, valves, aorta
	Orthopedic	Skull, spine, bone, muscles, fingers
	Orthodontic	Braces, brackets, palatal arches, files
	Surgical instruments	Catheters, scopes, suture
Home Appliances	SMA Springs	Rice cooker, Coffee maker, Automatic desiccator, Anti-scald valve, Water flow control valve, Bathtub adapter, Under floor vent

4. Machining of SMA

Major applications of SMAs are found in Automotive, Aerospace and Biomedical field. In this fields SMA applications need machining operation to convert raw material into complex shape product. Manufacturing of complex shape SMA product require machining with accuracy and precision. Machining of Shape Memory alloy is challenging due to its unique properties, presence of nickel and hardness of alloys [1]. In order to make SMAs suitable to its widespread applications in engineering field, research on SMAs should be focused to its machining and optimization of parameters. SMAs can be machined by Conventional and Non-conventional machining methods. Conventional and Non-conventional machining and its challenges are discussed in following section.

4.1 Conventional Machining

Conventional machining processes such as Turning, Milling, Drilling, Cutting and Grinding can be used for machining of SMA. However, [1], [2], [3] and [4] reported difficulty in machining by conventional methods due to its inherent material properties.Poor machinability characteristics such as high cutting pressures, higher specific cutting energy, high tool wear, and many burr forms during turning, drilling, and grinding are caused by these inherent features. Hassan et al. [6] study the conventional machining of SMA and observed the difficulties while machining such as burr formation and elasticity. In this study effect of various input parameters on Surface roughness of machined part is studied. Surface roughness is an important feature for the application of SMA. Several defects have been observed during machining of NiTi SMA on the work part such as cracking, tearing and surface drag. [7]

4.2 Non-conventional Machining

In Non-conventional machining methods, machining operation is performed by avoiding direct contact between machine tool and material. Non-conventional machining methods have overcome the difficulties reported in conventional machining of SMA. According to the desired properties of SMA for its specific application various non-conventional machining methods such as Electric discharge machining (EDM), Wire cut electric discharge machining (WEDM), Abrasive water jet machining (AWJ), Laser machining, Water jet machining (WJM) are used for machining. In wirecut EDM better machinability result obtained for the machining of SMA [8]. Instead of conventional machining process non-conventional machining process are widely used for the machining of complex shape SMA with accuracy and precision.

5. Optimization of Process Parameters

Optimization of input process parameters plays significant role in the quality of machining. Selection of input parameters and their level to get good quality of machining with minimum no. of experiments requires a systematic approach. Every optimization technique is having its own advantage and limitations. In the current study various optimization techniques such as Taguchi Method, Response Surface Methodology, GRNN, NSGA, and HTS Algorithm used for optimization of Wirecut EDM input parameters are discussed in the following section.

5.1 Taguchi Method

Taguchi is the statistical Method focuses on the quadratic quality loss function. In this method statistical measure of performance uses are Signal to Noise (S/N) ratio, Orthogonal Array (OA) and analysis of variance (ANOVA) .The Signal to Noise ratio consider both the mean and the variability into account. It is the ratio of the mean to the standard deviation. The Signal to Noise ratio is taken as Nominal, Lower and Higher as per the objectives. The parameter optimal setting is the parameter combination, which has the highest, lowest and nominal signal to noise ratio. Orthogonal array creates the various combination of input parameters and their level to perform experiments. Analysis of variance decides the contribution of each parameter in the output. Saeed Daneshmand et al. [9] optimized the Current, Gap Voltage, Pulse on time, Pulse off time to get desired value of Material removal rate (MRR) & Surface roughness (SR) by using Taguchi method in EDM of SMA. Highest value of MRR was obtained at highest level of all parameters except pulse off time at lower level. Pulse current and Pulse on time found two main and effective parameters which significantly contribute for higher MRR & lower SR. Gangele et al. [12] also optimized the surface roughness by using Taguchi technique in EDM of SMA. The input parameters considered are same as of Daneshnmand [9] except Duty cycle. Pulse off time is the common effective parameter found in both the papers. Minimum value of SR was obtained at maximum value of Pulse on Time and lowest value of Pulse off time and discharge current. These researchers [9,12] show that minimum value of surface roughness was obtained at maximum value of Pulse on Time. However, value of Pulse on Time varies from 80 to 150 micro sec.Discharge current is almost same for minimum value of SR. Abibi et al [11] study the Micro Electric discharge machining of NiTi alloy . Capacitance, Discharge Voltage & Electrode material were choosen for the study as input parameters. Through this optimization, they found that electrode material is the most significant parameter.

Reddy et al. [15], Kulkarni et al [16], Magbe et al. [17] and Rathi et al [18] optimized Wirecut EDM parameters for NiTi SMA. Pulse on Time and Pulse off time are common parameters in both the studies and found effective for desired output. Highest MRR was observed almost at the same value of Pulse on Time, Pulse off Time and Servo Voltage. In all studies, Pulse on Time varies from 110 to 125 micro second. It means Pulse on Time is equally affecting MRR. But for the Pulse off Time variation is too large. It varies from 9 to 35 micro second in both the studies. Effect of servo voltage is also observed same like Pulse off time. It varies from 40 to 50 V. Lowest surface roughness was observed at lowest value of Pulse on Time in every case but lot of variation found in values. It may be due to selection of different level of parameters and control of parameter range in different machines. The final optimized values in the above studies are closely matching. Optimized value of Pulse on Time was in the range of 100 to 125 Micro second. 10% variation was observed in Pulse off time and servo voltage. Chaudhari [19] designed the experiments for optimization of input parameters by using Taguchi L16 Orthogonal array and optimization were performed by using HTS algorithm. To increase MRR and decrease the SR, Nano powder mixed dielectric fluid was used and studied its effect. Due to this, MRR and SR was increased by 24.01% and 9.35% respectively.

5.2 Response Surface Methodology (RSM)

Response surface methodology is used to optimize and predict process and its variables. Effect of input parameters on the response variable can be studied in RSM. It is an iterative method. In this, iterations are move towards the optimum region considering any constraints. When initial solution is far away from the optimum, factorial experiments can be used. Designing of the factorial experiments helps to reduce no of experiments and systematically move towards optimum the. Various methods like CCD, Box Behnken are used to design experiments in RSM.

Sharma et al. [10] and Vinayak N. Kulkarni et al. [16] optimized the input parameters using Response Surface methodology. Results from both papers are closely matching with negligible variations. As discussed in previous papers [9,11,12] of EDM same pattern is found for Wirecut EDM that is highest value of MRR was obtained at highest value of Pulse on Time. Therefore, it can be concluded that Maximum MRR can be obtained at Highest Pulse on Time for Wirecut EDM and EDM of SMA. Pulse off time for Highest MRR is 125 and 130 micro second for [16] & [10] respectively. Servo voltage and Pulse off time values are at middle level for highest value of MRR. Lowest value of Surface roughness 1.33 µm and 1.43 µm were found at lowest Pulse on Time. Pulse current and pulse on time found main and effective parameters affecting the MRR & SR respectively. Chaudhari et al. [20] and [21] optimized the same input parameters with different grade of Ni Ti material in Wirecut EDM. The combine approach of RSM and HTS algorithm techniques used for optimization. Same input parameters and their range are used in both [20] and [21] papers. Pulse on Time and Current significantly affecting the Surface Roughness and Micro Hardness respectively, whereas Pulse off Time and current shows major effect on Material Removal Rate.

5.3 GRNN (General regression neural Network)

GRNN is used to optimize and predict the process and its variables. In this process variable data is preprocesses which is called Smoothing. Preprocessed data is required to predict the measure of performance in GRNN. GRNN is divided into four steps which is called layers namely input, pattern, regression and output. In first step input variable data were demonstrated in the given structure. In the second step (pattern) all input variable data was processed to keep number of experiments and number of neurons same. In third step extra neuron calculates the probability density function and fourth step (output) calculate the final result [13].

Mujumdar et al. [13] and [14] optimized responses such as surface roughness and microhardness by using GRNN and MOORA (Multi-Objective Optimization by Ratio Analysis). Same results obtained in both the methods. But prediction model developed by GRNN & MOORA Fuzzy logic found different prediction error ± 5% and ±10 % respectively.

5.4 Topsis (Technique for Order of Preference by Similarity to Ideal Solution)

In TOPSIS method distance between two types of solution is computed to find optimal solution. In this optimum solution has the shortest distance from the ideal positive solution and longest distance from ideal negative solution. These distances are calculated from the process variable data. In ideal positive solution profit criteria is maximize and cost criteria is minimized, whereas in ideal negative solution cost criteria is maximized and profit criteria minimized [25]. Hargovind Soni et al. [23] optimized Ti50 Ni40 Co10 of Wirecut EDM by using TOPSIS method. In this they studied the Pulse on time, Pulse off time, Servo voltage, Servo feed and Wire speed parameters. Optimal level of input parameters was found using TOPSIS method.

5.5 HTS Algorithm

Heat Transfer Search Algorithm (HTS Algorithm) is developed on the basis of heat transfer principle. In this principle system always works to be at thermal equilibrium state. Behaviors to achieve thermal equilibrium is simulated in Heat Transfer Search Algorithm. To reach the global optimum solution it uses set of solutions. It is the population-based algorithm. As any system always tries to attain its thermal equilibrium likewise in HTS algorithm it always tries to reduce difference between existing solution and optimum solution to optimize the solution. For any system to achieve its thermal equilibrium state, heat is transferred from system to surrounding through three modes namely conduction, convection and radiation. Out of these any medium can be used for transfer of heat. [26]

Chaudhari et al. [20] and [24] used combine approach of RSM and HTS algorithm for optimization in machining of SMA. In this they predicted and optimized the output variable at different set of input parameters. Pulse on Time and Current has the major effect on Surface Roughness and Micro Hardness respectively, whereas Pulse off Time and current were affecting on Material Removal Rate. HTS algorithm was effectively used to predict the output with +/- 3% to 5% error.

Fig 1 shows the Optimization technique wise no papers published in the literature. Maximum no of papers published on optimization in machining of SMA using Taguchi Method followed by RSM. There is further scope to explore following optimization technique in the machining of SMA.

- Artificial Neural Network (ANN)
- Teaching Learning based algorithm (TLBO),
- Jaya Algorithm
- Genetic Algorithm
- Simulated Annealing
- Artificial Bee Colony
- Ant Colony Optimization (ACO)
- Particle swarm optimization (PSO)

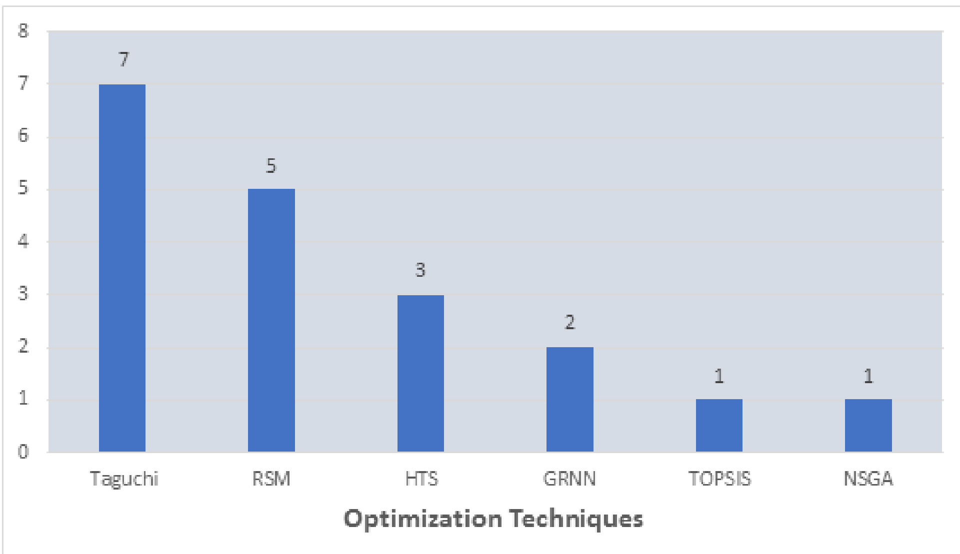

Fig.1. Optimization technique wise no. of publication for WEDM of SMA

Table1 presents summary of research works carried out on machining of shape memory alloy using Wirecut EDM processes showing the details of Process, Workpiece material, Input parameters, Output parameters, Techniques and Remark.

Table 1- Research work in Wirecut EDM of SMA

Author	Process	Material	Input Parameter	Output Parameter	Technique	Remark/result
Saeed Daneshmand et al (2014)[9]	EDM	NiTi	Pulse current, gap Voltage, Pulse on time, Pulse off time	MRR & SR	Taguchi	Pulse current & Pulse on time are the Significant input parameters having major effect on output.
Sharma et al. (2017) [10]	WEDM	Nitinol	Pulse-on time, Pulse-off time,Servo-	SR, Dimensional Accuracy.	RSM	Got better machining result through optimization

			gap voltage, Discharge current			
Mustafa Haider Abibi et al (2017) [11]	Micro EDM	NiTi	Capacitance, Discharge Voltage, Electrode material	Overcut, Taper Angle, SR	Grey Taguchi method	Multi response optimization were carried out to achieve several objectives at a time.
Anshul Gangele et al (2018) [12]	EDM	NiTi	Pulse on time, Pulse off time,Discharge current, Duty cycle	Surface roughness	Taguchi	Lowest value of SR find out by optimizing the input parameters.
Himadri Mujumdar et al (2018) [13]	WEDM	NiTi	Pulse on time, discharge current, wire tension, wire speed, Flushing pressure	Roughness, Max peak to valley height , RMS roughness, micro hardness	GRNN, VIKOR method, Fuzzy logic	Study the effect of various input parameters on output. Pulse on Time has the major effect as compared to other parameters.
Himadri Mujumdar et al (2018) [14]	WEDM	NiTi	Pulse on time, discharge current, wire tension, wire feed, Flushing pressure	Surface roughness Micro hardness	GRNN, MOORA Fuzzy logic	Discharge current has the major contribution to get minimum surface roughness.
Divvya Reddy et al (2018) [15]	WEDM	Ti50Ni48 Co2	Pulse-on time Pulse-off time Servo voltage	MRR & SR	Taguchi	Optimization of input process parameters were carried out along with microstructural analysis.
Vinayak N. Kulkarni et al (2018) [16]	WEDM	NiTi	Spark gap Voltage, Pulse on time, Pulse off time	MRR & TWR	Taguchi	Pulse on Time and Pulse off Time found most significant parameters.
Remond Magbe et al (2019) [17]	WEDM	Ni55.8Ti	Spark gap Voltage, Pulse on time, Pulse off time & wire Feed	MRR, Surface quality (surface roughness depth)	Taguchi & NSGA II	Higher value of voltage, Pulse on time & wire feed rate results maximum MRR
Piyush Rathi, (2019) et al [18]	WEDM	Ni55.8Ti	Pulse on time Pulse off time Discharge Current	MRR & SR	Taguchi-GFA approach	Input parameters selected for the study has significant contribution in output.
Rakesh Chaudhari (2019)et al	WEDM	Ni55.8Ti SMA	Pulse on time, Pulse off time, Discharge	MRR & SR	RSM & HTS algorithm	Maximum value of MRR were identified using contour plots.Shape

[19]			current			Memory Effect studied with the help of DSC test.
Rakesh Chaudhari et al (2019) [20]	WEDM	Ni55.8Ti Superelastic	Pulse on time, Pulse off time Discharge current	MRR & SR Micro hardness	RSM & HTS algorithm	Shape memory effect ensure through DSC test and optimize the input parameters.
Rakesh Chaudhari et al (2019) [21]	WEDM	Pure Titanium	Pulse on time, Pulse off time Discharge current	MRR & SR	RSM-GRA analysis	current has the major effect on MRR.
Vinayak N. Kulkarni et al (2020) [22]	WEDM	Ni Ti	Pulse time, pause time, wire feed, and servo voltage	SR, MRR & Toll wear rate	RSM & MDE	In all the optimized input parameters Servo voltage has the major contribution in the process.
Hargovind Soni et al (2020) [23]	WEDM	Ti50 Ni40 Co10	Pulse on time, Pulse off time, Servo voltage, Servo feed and Wire speed	Material removal rate and Average roughness	TOPSIS	Optimal level of input parameters were found using TOPSIS method.
Rakesh Chaudhari et al (2021) [24]	WEDM	NiTi	Current, pulse-on time, pulse-off time, and nano-graphene powder concentration	MRR & SR	Taguchi & HTS	MRR increases because of increase in Nano-graphene powder concentration

From the literature review study , it was found that the most of the authors have used the Taguchi and RSM methods for optimizing parameters. Limited literature was reported on other optimization techniques such as TOPSIS, HTS, and GRNN. Other than the above discussed method various other optimization techniques can be explored for optimization in machining of SMA. Artificial Neural Network (ANN), Teaching Learning based algorithm (TLBO), Jaya Algorithm, Genetic Algorithm, Simulated Annealing, Artificial Bee Colony, Ant Colony Optimization (ACO) and Artificial intelligence methodologies like Particle swarm optimization (PSO) have not been reported by any authors. So, there is further scope to explore more accurate optimization by using other optimization techniques. In many studies pulse on time, pulse off time, and discharge current were found significant parameters for the process.

6. CONCLUSIONS

Shape memory alloys has the wide variety application in the field of Automotive, Biomedical, Robotics and Communication Engineering. All of these SMA applications need good quality of machining for final product. It can be achieved through optimization of machining parameters. Optimization saves the time and cost for performing machining processes. For optimization in the machining operation of shape memory alloys, the Taguchi and RSM methods are frequently employed. Very few authors mentioned any other optimization strategies. For the machining of shape memory alloy, more optimization methods need to be investigated. Pulse on Time, Pulse off time, and current were found to be significant parameters that have a major effect on the outcomes of machining. Better optimization results may be obtained using newly created Artificial Intelligence based optimization strategies.

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