Machining of Shape Memory Alloys by using WEDM

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Abstract

NITINOL is a newly developed material. It possesses the properties as high fatigue strength, high malleability and high toughness. So machining of such materials is very difficult due to above properties. Thus there is necessary to study the machining methods which use appropriate feed, cutting speed and also considering the machining parameters. A non-conventional machining method Wire electrical discharge machining (WEDM) is used to cut hard to machine materials which are difficult to machine by traditional processes. WEDM is thermal machining process capable of accurately machining parts with difficult shapes and more hardness, which have sharp edges that are very difficult to be machined by the traditional machining processes. WEDM is worked on sparking phenomenon of EDM and used as non-contact type material removal process.

Keywords: Material Removal Rate, Micro Hardness, Surface Roughness, WEDM

I. INTRODUCTION

Ti Ni alloy are an important class of shape memory alloy (SMA’s). Nowadays these materials are applicable in different fields such as dentistry, medicine, aerospace, and automobile industry [1]. NITINOL is alloy of nickel and titanium. High toughness and high fatigue strength are property of NITINOL. Therefore, difficult to machine by conventional machining process. Machining of such material by conventional machining process effects on machining parameters of NITINOL surface.

Nitinol is a shape memory alloy possesses the shape memory effect. Shape memory alloys are a kind of active materials; they have special characteristics in comparison with other alloys. Shape memory alloys can respond properly and adjust themselves in the best way with the environmental changes. Sensibility, high damping, adaptive responses, memorized capability and super elasticity are properties of Shape memory alloys. If a small percentage of deformation occurs with determined chemical composition of shape memory alloy and the alloy can regain its original shape when it is heated above its deformation temperature. Deformation temperature is the phase transformation temperature of austenite to marten site and vice versa. Nickel-Titanium is the most important combination of smart alloys and includes special properties which differentiate it from other materials. High strength and hardness are the mechanical properties appear by the shape memory alloy.
In the manufacturing Machinability of TiNi shape memory alloy has become an important point. Due to low thermal conductivity and chemical reactivity there is very difficult to machining of such material. Productivity is an important phenomenon in the machining process. High cutting speed gives higher productivity. Due to greater tool wear rate, high surface hardness and poor surface quality the machining of such at higher speed is difficult [2].

The demand for material having high hardness, toughness and impact resistance are increasing. By conventional machining methods these materials having high hardness are difficult to machine. The machining is not easy task for such material. So we can do machining task of such material very easily by using non-conventional machining method. Electrolytic grinding, supersonic machining and electrical discharging machining (EDM) are the non-conventional machining method. Non-–conventional machining process used for machining a complex and intricate shape and profile is Wire electrical discharge machining.

In recent year to meet the requirement of manufacturing field especially for die industry WEDM machining process has been significantly improved. WEDM Involve a series of complex physical processes which include heating and cooling. The most important performance measures in WEDM are surface roughness (SR), material removal rate (MRR), and micro-hardness. Discharge current, discharge capacitance, wire speed, pulse duration, average working voltage, pulse frequency, wire tension and dielectric flushing conditions the machining parameters that mostly affect these performance measures.

II. MACHINING OF SMAS BY WIRE ELECTRO DISCHARGE (WEDM)

A controlled metal-removal process that by means of electric spark erosion is used to remove metal in the Electrical Discharge Machining (EDM). In this process, the cutting tool is used as an electric spark to cut (erode) the workpiece to produce the finished part of required shape. By applying a pulsating (ON/OFF) electrical charge the metal-removal process is performed at high-frequency current through the electrode to the workpiece. This removes very small particles of metal from the workpiece at a controlled rate.

III. SURVEY OF WORK DONE IN RESEARCH AREA

In the wire electrical discharging machining (WEDM) process, a thin wire as an electrode, transforms electrical energy to thermal energy for cutting materials. With the help of this machining process we can machine alloy steels, conductive ceramics and aerospace parts apart from their hardness and toughness.

The wire EDM machining process is capable of producing a good, corrosion-resistance, precise, and wear-resistance surface. The white layer caused by EDM process increases surface roughness. Due to this surface become hard and brittle and decreases the wear resistance, corrosion and fatigue strength of the workpiece. Due to electrical spark the surface quality will be reduced and large energy may cause change in structure and physical properties of material also result in crack.

A. Material removal rate (MRR) in WEDM:

The productivity of any manufacturing industry is depending on the Material removal rate. MRR is defined as amount of material is removed from workpiece under working time (mm³/ min or mg/ min)[15]. TiNi alloys are superior ductility, fatigue strength and corrosion resistance has resulted in many applications. The basic characteristics of TiNi SMAs involving transformational crystallography, shape memory phenomena and the effects of thermo mechanical treatments have been investigated intensively.
TiNi alloys can be tensile-deformed in a ductile manner to about 50% strain prior to fracture but the high toughness, severe strain hardening, and viscosity. The unique pseudoelastic behavior has caused the machining characteristics of TiNi SMAs to be quite complicated. Some special techniques have been used to overcome this difficulty in machining of TiNi SMAs such as wire-cut machining, electric-discharge and laser machining.

Material removal rate for non-traditional machining is less as compared to conventional machining process. But it affects by above mentioned properties. In the study to determine the influence of parameters on the Ti35.5Ni49.5Zr15 the effect of some of the most of the parameters affected in the EDM process on a NiAlFe ternary alloy including discharge current \( I_p \) and pulse duration \( \tau_p \). Figure 1 shows the material removal rate (MRR) versus the pulse duration at \( I_p = 10A \) for Ni60Al24.5Fe15.5 and Ti35.5Ni49.5Zr15 alloys [13]. As can be seen from Fig.1, the MRR of Ni60Al24.5Fe15.5 alloy is larger than that of Ti35.5Ni49.5Zr15 alloy at various pulse durations during the EDM process.

![Material Removal Rate vs Pulse Duration](image1)

Fig. 1: The material removal rate vs. the pulse duration \( \tau_p \) at \( I_p = 10A \) for the Ni60Al24.5Fe15.5 and Ti35.5Ni49.5Zr15 alloys.

**B. Surface Roughness:**

Surface roughness is a machining parameter that plays a very critical role in determining the quality of engineering components. A good quality surface improves the wear resistance, corrosion and fatigue strength of the workpiece [3].

The white layer formed by EDM process increases surface roughness, makes the surface become hard and brittle, and decreases the fatigue strength, corrosion and wear resistance of the workpiece. Eventually, the surface quality and life of the workpiece will be decreased [14]. To improve surface quality and achieve an optimal surface roughness in finishing process, the oxidation due to electrolysis should be retained together with a lower energy input.

![Surface Roughness vs IP x TP](image2)

Fig. 2: The surface roughness vs. the product of \( I_p \) and \( \tau_p \) for the EDMed Ni60Al24.5Fe15.5 and Ti 35.5Ni49.5 Zr 15.5 alloys [13]

![Surface Roughness vs Pulse Duration](image3)

Fig. 3: shows the roughness of EDM machined surface roughness Vs the pulse duration \( \tau_p \) at various discharge currents \( I_p \) for the Ni60Al24.5Fe15.5 alloy. The surface roughness of the machined surface changes from 1.5 to 3.8 \( \mu m \). This result indicates that the increased pulse duration and discharge current increase the roughness of EDMed surface. High-discharge current produce the large
amount of discharges to strike the workpiece surface more intensely and the resulting worsened erosion effect brings about a deterioration of the surface roughness. After that, the longer pulse duration gives greater discharge energy for melting and penetrate deeper into the material, which formed larger and deeper discharge craters, leading to an increased surface roughness on the workpiece [13]. During machining on WEDM there is the electric field becomes stronger by increase of voltage and easily the spark discharge takes place under the same gap and a coarse surface is always obtained. So that peak current is most affected parameter on surface roughness. For better surface roughness there is necessary to find out optimum value of such process parameters.

C. Micro Hardness:

The EDM process systematically induces an increase the hardness of the outer layers, of machined surfaces. The increase in rate depends on the type of the machined material [12]. The change of micro hardness from outer layer of material to inner depth creates some surface integrity issues. Outer surface layer hardness is also varies by chancing electrode material. It creates the recast layer on the machined surface which is also known as white layer. The recast layer possesses a property like changing hardness from outer layer of material to inner depth.

Fig. 3 reveals the specimen’s hardness at various distances from the EDMed surface of the Ni$_{60}$Al$_{24.5}$Fe$_{15.5}$ alloy under the conditions of $I_p = 10A$ and $\tau_p = 100\mu s$. It indicates that the specimen’s hardness at the outer surface can reach 527 Hv. This hardening effect arises from the formation of the oxides Fe$_2$O$_3$, Al$_2$O$_3$, NiO and the deposition particles in the recast layer [13].

![Graph showing Micro Hardness](image)

Fig. 3: The specimen’s hardness at various distance from the EDMed surface of Ni$_{60}$Al$_{24.5}$Fe$_{15.5}$ alloy under the condition $I_p = 10A$ and $\tau_p = 100\mu s$.

IV. RESULTS AND DISCUSSION

- Material removal rate is increased with increase in pulse duration and after some time it goes on decreasing with increasing pulse duration. Thus peak current and pulse duration are most affecting process parameter on material removal rate.
- Recast white layer is formed on the EDMed machined surface. The surfaces are heavily rough because of the debris which are not flashed away completely from the machining zone. It indicates that the specimen’s hardness near the outer surface can reach maximum than core hardness, but this hardening effect is due to the formation of the oxides.
- During machining on WEDM there is increase of voltage means that the electric field becomes stronger and the spark discharge takes place more easily under the same gap and a coarse surface is always obtained. So that peak current is most affected parameter on surface roughness.

V. CONCLUSION

The references presented above reveal that the WEDM of SMAs have been reported on the effect of discharge voltage, discharge current and pulse duration on the responses. The research represented above is topography characteristics like material removal rate, surface roughness, microhardness. Very little work has been done on TiNi SMAs using WEDM and optimization of process parameters. As there is need to study the effect of parameters in WEDM on SMAs and optimize the WEDM process parameter.

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