Ultrasonic-Assisted Turning of NiTi Shape Memory Alloy

J. Akbari, A.G. Chegini, A.R. Rajabnejad
Center of Excellence in Design, Robotics, and Automation,
School of Mechanical Engineering, Sharif University of Technology,
Azadi Ave., Tehran, Iran

Abstract

This experimental investigation is on the ultrasonic vibration enhancement and study on chip removal mechanism regarding the utilization appropriate tool for turning NiTi based shape memory alloy (SMA). For this purpose, a special wave concentrator was designed and fabricated. FEM analysis was performed on the ultrasonic head for finding the optimum profile for the horn. The experiments were performed on SMA and steel to compare the results of ultrasonic-assisted turning with conventional turning. It was found out that the acceleration caused by the ultrasonic vibration, helps in chip generation and improves the surface quality and decreases the cutting force components.

Keywords:
Ultrasonic, Turning, Shape memory alloy

1 INTRODUCTION

Shape memory alloys (SMA) such as NiTi (Nitanol), generally are being used in medical, robotics and military industries, due to their excellent mechanical and memory properties. The applications of shape memory alloys are increasing day by day, particularly in robotics as compare to other branches of engineering sciences. Beside the aforementioned properties of Nitanol, they have few uncommon piezoelectricity and suitable mechanical characteristics [1]. Hardening due to strain and uncommon piezoelectricity behaviour, toughness and high viscosity, lead to complexity in shape memory alloy machining. The main drawback of such alloys which makes the use of Nitanols very difficult could be their extra toughness and less machinability.

To overcome to the above problems associated with the use of Nitanol, new machining techniques have to be applied. In this research, in order to the ease of material removal, and to conquest these difficulties and ultimately, surface quality improvement, ultrasonic vibration were added to the process of machining. This technique, leads to considerable improvement of cutting process of low machinability materials, such as high strength alloys used in aerospace, super alloys and composites, comparing with the conventional methods of turning. Reviewed articles showed that the conventional machining of shape memory alloys has only done by reference [2]. In this reference, the results of turning, drilling and deep drilling of SMA have been discussed.

The history of studying the effects of ultrasonic vibrations on machining process goes to 50 years ago. Kumabe and Masuko showed, if the cutting force is, in the form of pulses, that results in reduction of cutting forces, reduction of tool temperature and thus improvement of tool life [3]. They also performed few experiments on cast iron, and different types of steel, along with experiments on finishing and gear machining, using ultrasonic vibrations comparing with the static status. In 1969, Skelton, used magnetostrictive transducer, which works with cyclic expansion and contractions [4]. He conducted his experiments by imparting the vibrations to the tools in two directions of feed and cutting speed. The result of the experiment was the reduction of machining forces as compared to conventional turning.

Shamoto and Moriwaki studied Elliptical Vibration Cutting (EVC) using planar ultrasonic vibrations [5,6]. They showed the reduction of machining forces and concluded that the simultaneous application of ultrasonic vibrations in two directions is much useful and efficient.

Babitsky and co-workers also widely examined the turning through ultrasonic vibrations [7-14]. They performed many experiments for turning of different materials with the help of ultrasonic vibrations. The ability of using ultrasonic vibrations in super alloys drilling had been proved by Azarhoushang and Akbari [15].

In this research the application of ultrasonic vibrations in feed direction and the effects of this noble technique on turning of Nitanol are studied. Machining results are compared with mild steel turning under the same cutting conditions.

2 PROCESS OF TURNING OF SHAPE MEMORY ALLOYS USING ULTRASONIC VIBRATIONS

Ultrasonic cutting is a non linear process, using shock vibrations which had been theoretically well developed [9]. Ultrasonic vibrations can be used in three main directions in turning process (Figure 1).

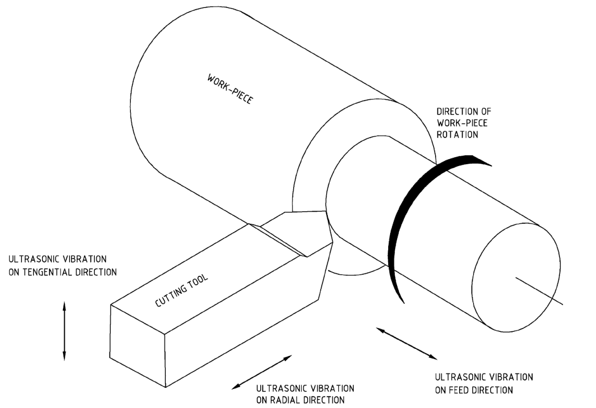


Figure 1: Three main directions of ultrasonic vibration[9].

5th International Conference and Exhibition on Design and Production of MACHINES and DIES/MOLDS
18-21 JUNE 2009 Pine Bay Hotel - Kusadasi, Aydin, TURKEY

Advantages of using ultrasonic vibration in both radial and tangential directions have been studied in [4]. Indeed the best condition achieves once the edge of the tool or the workpiece are vibrated to cause an intermittent cutting. As shown in Figure 1, three main directions for applying ultrasonic vibrations could be: 1. feed direction, 2. tangential direction and 3. radial direction. However the applications of ultrasonic radiations in feed direction that is called "sweep cutting" in [9], was reported to be more effective and thus was used in this study.

3 EXPERIMENTAL EQUIPMENT AND ULTRASONIC VIBRATIONS HEAD

As shown in Figures 2 and 3, workpiece is fixed by the chuck of a Tabriz TN50D turning machine. To generate a vibration of 10 µm amplitude in the tip of the tool, an ultrasonic transducer (with frequency of 21.5 kHz) and a generator with the power of 1200W (Masterosonic MSA 2339) were used. Tool geometry includes CCMT060204 with grade of TP40 (SECO) and F2 chip-breaker were selected. During the experiments, the cutting force (using a Kistler 9253B Dynamometer) and the surface roughness (TIME-TR200) data were collected (Figure 3). According to Figure 2, the ultrasonic head consists of: horn (wave concentrator), booster, transducer and generator. The components were controlled automatically to maintain the ultrasonic head in resonance position. The ultrasonic head components are discussed in the following.

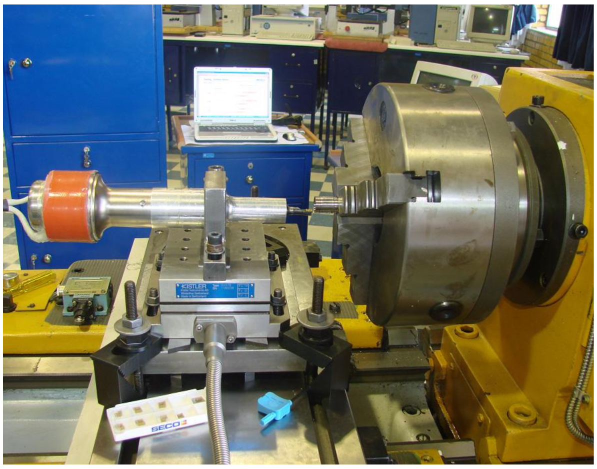


Figure 2: Experimental setup

Finite element analysis has an important effect on design and construction of the horn and booster. Therefore, ANSYS® software was used for finding the best profile and doing modal analysis for finding the nodal point for clamping (Figure 4). After primary design, parametric modelling was performed, in order to final optimization. For this, the main parameters in SolidWorks® software were determined and general design was done and manufacturing drawings were generated. Among different parameters, selection of type of tool holder, internal or external turning applicability, the insert grade, the coating and geometry of insert (including tip angle of insert, tool angles and type of chip breaker) to tolerate the ultrasonic vibrations are of great importance. With respect to space limitations, series of small type boring holder were used that could accept also the external turning inserts. For instance, among these inserts, CCMT with boring geometry (ID) with tool holder SCLCR06-S08K, is an example [16].

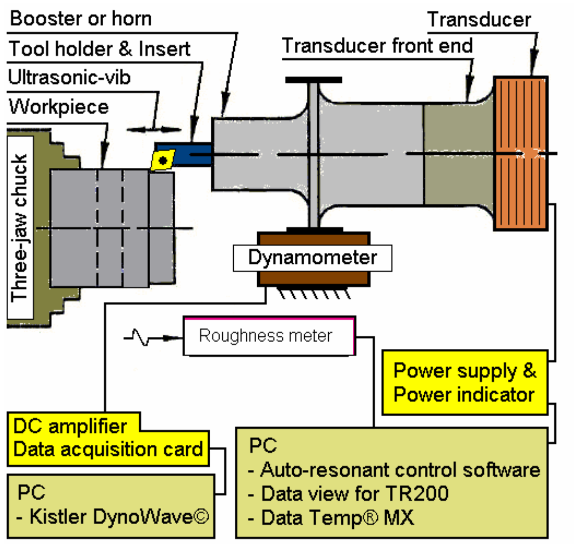


Figure 3: Schematic view of setup including electronic instrumental block diagram

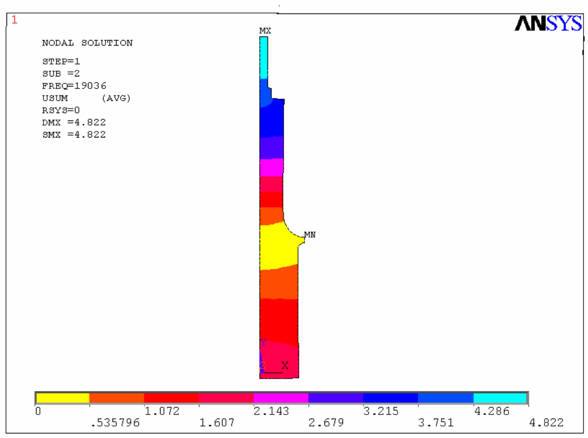


Figure 4: Results of modal analysis of the ultrasonic head

4 MACHINABILITY OF SHAPE MEMORY ALLOY

Nitinols or NiTi, are the major group of shape memory alloys, though having high ductility, also have sufficient strength for creep, fractures and good resistance against corrosion, which lead to enormous applications of the alloy. NiTi alloy in a ductile behaviour can resist up to 50% of strain, before fracture, but hardening due to strain and uncommon toughness piezoelasticity and high viscosity, may cause very complex behaviour in NiTi alloy while machining. Figure 5 shows some drawbacks while machining of NiTi alloy during grinding and turning processes of conventional machining [2]. To overcome these problems, new techniques have to be used, such as laser assisted machining, electro discharge machining (EDM) and wire EDM. Though each of these machining techniques have their own limitations, but for solving the problem, it is necessary to realize the characteristics of mechanical machining of NiTi [1,2]. In this study, under the same condition, mild steel was used as a model to compare the results.

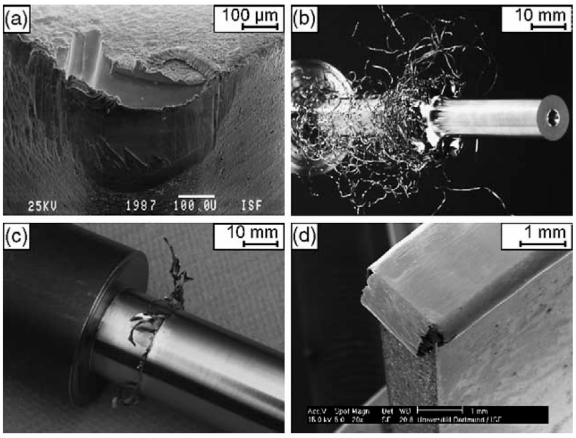


Figure 5: Problems while machining of Nitanol alloy. a) tool wear b)chip sticking c,d)burr generation after turning or grinding [2].

5 EXPERIMENT RESULTS AND DISCUSSION

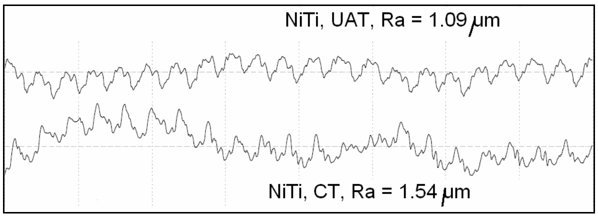
5.1 Surface profile analysis

It was evident that surface roughness of the machined workpiece, was depended on the conditions of machining. Figure 6, shows the machined surface profile and roughness of shape memory alloy and mild steel at the same feed rate and tool geometry. In each case, the upper profile shows the surface topology after machining by ultrasonic vibrations, and the lower profile, shows the surface topology after conventional machining. As can be seen in the figure, once the ultrasonic vibrations are being used, the surface smoothness improved in both cases, which is comparatively more effective in the steel sample. The obtained results are quite similar to the other researchers' reports [4,8]. Indeed, using ultrasonic vibration, surface roughness showed considerable improvement along the working axis. It was obvious that the improvement of surface quality is due to the conversion of conventional turning to semi-interrupted cutting process along with high frequency impulses [8]. This led to dynamic stiffness of workpiece, tool and machine set, which consequently increased the machining accuracy. Another reason of imparting the quality of surface, especially in low cutting speeds, could be omitting of build-up edge in the presence of ultrasonic vibration [8,17].

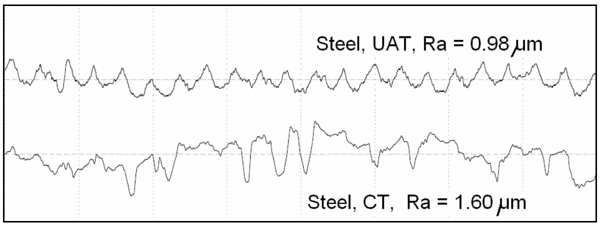
5.2 Surface roughness vs. cutting speed

Figure 7 compares the surface roughness of machined surface in different cutting speeds, in the presence of ultrasonic vibrations and, without the use of ultrasonic. Although the amount of surface roughness in UAT (Figure 7b) for steel is somehow independent of cutting speed, because of the aforementioned reasons, the surface quality of UAT is quite better than conventional turning method.

Thereby, in case of shape memory alloy, in the cutting speed range of 30-45 m/min and higher than 80 m/min for the mentioned tools, UAT led to achieve best surface quality. It is interesting to compare the recommended cutting speeds by the tool manufacturer with our experimental results. The tool catalogue recommends the range of cutting speed about 25-50 m/min for mentioned material and selected tool [17]. As can be seen in the Fig. 7, the first range of roughness improvement 30-45 m/min is almost overlaps with the catalogue recommendation. In the other word, the selected tool was very suitable for turning, using ultrasonic vibrations and even beyond the recommended range that is more than 80 meter/minute the tool was capable of being used.

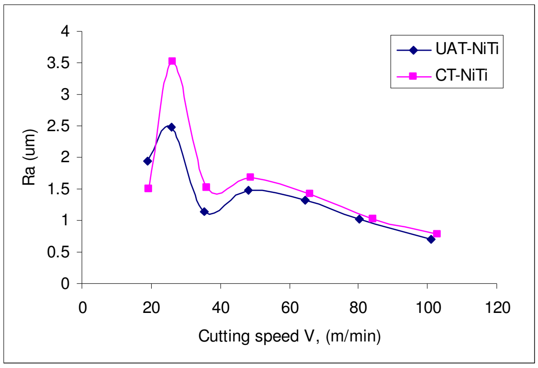


(a)

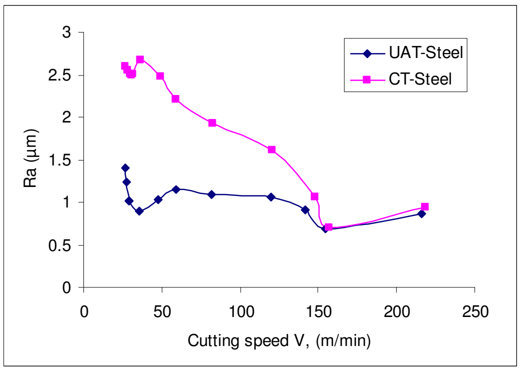


(b)

Figure 6: Surface profile of machined surface, feed 70 µm/rev (a): Work material NiTi, Cutting speed 36m/min, depth of cut 0.15 mm, (b) Work material mild steel, cutting speed 120 m/min, depth of cut 0.2 mm.



(a)



(b)

Figure 7: Variation of surface roughness vs. cutting speed, Feed 70 µm/rev, a) NiTi, depth of cut 0.2 mm, b) Steel, depth of cut 0.15 mm

6 SUMMARY AND CONCLUSIONS

The effect of using ultrasonic vibration during turning of shape memory alloy (Nitanol) was studied. The results can be summarized as:

- Using ultrasonic vibrations in cutting speed range of 25-100 m/min, 20-70% improvement of surface smoothness was obtained.
- In case of mild steel, during UAT the surface smoothness improved to 130% in cutting speed range of 25-220 m/min.
- The scattering of surface roughness parameters in turning process, using ultrasonic vibrations (UAT), was comparatively less than the conventional turning (CT) method.

7 REFERENCES

[1] Chegini, A.G., 2008, Ultrasonic assisted turning of NiTi shape memory alloy, Thesis of Master of Engineering, Sharif University of Technology, Iran.

[2] Weinert, K., Petzoldt, V., 2004, Machining of NiTi based shape memory alloys, Materials Science and Engineering A 378, 180–184.

[3] Kumabe, J., Masuko, M., 1958, Study on the ultrasonic cutting, JSME24 (138) 109-114 (in Japanese).

[4] Skelton, C., 1969, Effect of ultrasonic vibration on the turning process, Int. J. Mach. Tool Design Res. 9, 363–374.

[5] Shamoto, E., Moriwaki, T., 1994, Elliptical vibration cutting, Annals of CIRP 43, 35–38.

[6] Shamoto, E., Moriwaki, T., 1999, Ultrasonic-precision diamond cutting of hardened steel by applying ultrasonic elliptical vibration cutting, Annals of the CIRP 48, 441–444.

[7] Babitsky, V.I., Kalashnikov, A.N., Meadows, A., 2003, Ultrasonically assisted turning of aviation materials, J.Mat.Proc.Tech 132, 157-167.

[8] Mitrofanov, A.V., Babitsky, V.I., Silberschmidt, V.V., 2004, Thermomechanical finite element simulations of ultrasonically assisted turning, Comput. Mater. Sci. 32 () 463–471.

[9] Babitsky, V.I., Mitrofanov, A.V., Silberschmidt, V.V., 2004, Ultrasonically assisted turning of aviation materials: simulations and experimental study, Ultrasonics 42, 81.

[10] Babitsky, V.I., Astashev, V.K., Kalashnikov, A.N., 2004, Autoresonant control of nonlinear mode in ultrasonic transducer for machining applications, Ultrasonics 42, 29–35.

[11] Mitrofanov, A.V., Ahmed, N., Babitsky, V.I., Silberschmidt, V.V., 2005, Effect of lubrication and cutting parameters on ultrasonically assisted turning of Inconel 718, J. Mat. Proc. Tech 162, 649-654.

[12] Ahmed, N., Mitrofanov, A.V., Babitsky, V.I., Silberschmidt, V.V., 2006, Analysis of material response to ultrasonic vibration loading in turning Inconel 718, J. Mat. Scince. Eng. A424, 318-325.

[13] Ahmed, N., Mitrofanov, A.V., Babitsky, V.I., Silberschmidt, V.V., 2007, 3D finite element analysis of ultrasonically assisted turning, Computational Materials Science 39, 149–154.

[14] Babitsky V.I., et al., 2007, Vibration excitation and energy transfer during ultrasonically assisted drilling, Journal of Sound and Vibration, doi:10.1016/j.jsv.2007.03.064.

[15] Azarhoushang, B., Akbari, J., 2007, Ultrasonic-assisted drilling of Inconel 738-LC, Int. J. Mach. Tools Manuf. 47, 1027–1033.

[16] SECO tools, 2006, MN2006_turning_GB_Inlay turning tools catalogue, 26-30.

[17] Chen, W., 2000, Cutting forces and surface finish when machining medium hardness steel using CBN tools, Int. J. Mach. Tools Manuf. 40, 455–466.