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COMPOSITES THEORY AND PRACTICE

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ELECTRO-DISCHARGE MACHINING OF TYPE H13 TOOL STEEL TITANIUM CARBIDE COMPOSITES

One of the most popular steels which have been used for tools in the hot metal extrusion process is AISI type H13 hot work tool steel. Although this steel has relatively good properties - wear resistance and hot toughness - it is no longer completely satisfactory because new extrusion materials place higher demands on extrusion tooling, and H13 type steel in its current form is not optimal. The paper presents the proposition of improving the properties of H13 type steel by introducing hard ceramic particles as reinforcement to the structure. Such composites consist of a modified H13 steel matrix and TiC particles of 0, 10, 20 and 30 volume percent. The composites were manufactured by the powder metallurgy method. The atomized matrix powder was mixed with a TiC powder using a Tubular mixer for 60 min. The mixed materials were consolidated by Hot Isostatic Pressing (HIP). Prior to the HIP process, the powder materials were placed in a steel can. The conditions of hot isostatic pressing for the modified H13 tool steel matrix composites were: temperature 1150ºC, time 4 hours and pressure 100 MPa. Particle reinforced metal matrix composites are difficult to machine using conventional manufacturing processes due to high tool wear caused by the hard reinforcement, even those tools which are made of cemented carbides. One of the best methods of machining of composite dies is sink electro-discharge machining EDM or wire electro-discharge machining WEDM. This work concerns the investigation into the machinability of Titanium Carbide (TiC) particle reinforced modified H13 steel using wire electro discharge machining (WEDM). WEDM cutting was conducted using a machine equipped with a RC type relaxation generator. The dielectric used in this experiment was deionized water. As the tool material, brass wire with a diameter of 0.25 mm was used. To compare, wrought H13 steel was also machined. The machining parameters such as pulse time and load voltage were varied in order to optimize the metal removal rate and surface integrity. The obtained results indicate that MMCs can be machined using WEDM although the metal removal rates are lower compared to conventional machining processes. It is shown that the surface roughness increases with higher discharge energy and decreases with the volume fraction of the reinforcement. The optimum machining rate considering the roughness and cutting rate, was when the pulse on-time is at 1.5 μs, pulse off-time at 10 μs and load voltage at 122 V.

Keywords: tool steel, composites, TiC particle, electro discharge machining WEDM, material removal rate

OBRÓBKA ELEKTROEROZYJNA KOMPOZYTÓW STAL NARZĘDZIOWA H13-WĘGLIK TYTANU

W procesie wyciskania na gorąco jedną z najczęściej stosowanych stali na matryce jest stal narzędziowa do pracy na gorąco typu H13 (wg AISI). Ta stal charakteryzuje się stosunkowo dobrymi własnościami: odpornością na zużycie i odpornością na pękanie na gorąco. Jednak wobec stale rosnących wymagań odnośnie do podwyższonych parametrów wyciskania i większej wydajności procesu jej własności pozostają nie w pełni zadowalające. W artykule przedstawiono propozycję podwyższenia jej własności przez wprowadzenie do struktury twardych ceramicznych cząstek. Jako fazę zbrojącą zastosowano cząstki TiC w ilości 10, 20, 30% obj. Do wytworzenia kompozytów zastosowano proces metalurgii proszków, w którym proszki osnowy i proszki fazy zbrojącej mieszano, a następnie prasowano metodą izostatyczną na gorąco HIP. Warunki prasowania: temperatura 1150ºC, czas 4 godziny i ciśnienie 100 MPa. Jak wiadomo, kompozyty metalowe są trudne w obróbce mechanicznej z uwagi na obecność w osnowie twardych cząstek zbrojących, które powodują intensywne zużywanie ścierne ostrzy narzędzi. Jedną najbardziej obiecujących metod obróbki kompozytowych matryc do wyciskania jest obróbka elektroerozyjna w obu znanych odmianach: drążenia wgłębnego EDM i wycinania drutowego WEDM. W prezentowanej pracy do obróbki kompozytów zastosowano wycinanie WEDM. Użyto wycinarki elektroerozyjnej zaopatrzonej w generator typy RC. Narzędzie obróbcze stanowił drut mosiężny o średnicy 0,25 mm. Obróbkę prowadzono w wodzie dejonizowanej. Przebieg obróbki kompozytów porównywano z przebiegiem obróbki stali handlowej H13 i spiekanej (MH13). Jako podstawowe parametry obróbki przyjęto czas trwania wyładowań (impulsu) i napięcie w impulsie. W funkcji tych wielkości optymalizowano wydajność obróbki i chropowatość uzyskanych powierzchni. Badania wykazały, że obróbka kompozytów jest mniej wydajna niż w procesie obróbki mechanicznej. Chropowatość powierzchni rośnie wraz ze wzrostem energii pojedynczych impulsów i ulega obniżeniu dla kompozytów z największą zawartością TiC. Określono najkorzystniejsze warunki obróbki WEDM badanych kompozytów: czas trwania impulsu 1,5 μs, czas przerwy pomiędzy impulsami 10 μs i napięcie robocze 122 V.

Słowa kluczowe: stal narzędziowa, kompozyty, cząstki TiC, obróbka elektroerozyjna WEDM, wydajność obróbki

INTRODUCTION

A number of steels types have been used for the production of tools in the hot metal extrusion process, nevertheless, one of the most popular is AISI type H13 hot work tool steel [1]. Although this steel has relatively good properties - wear resistance and hot toughness - it is no longer be completely satisfactory because new extrusion materials place higher demands on extrusion tooling [2], and H13 type steel in its current form is not optimal. The choice goes to modified H13 steel reinforced with particles of 0, 10, 20 and 30 volume percent TiC. Such composites were manufactured in this research by the powder metallurgy method.

As compared with conventional metals and alloys, metal matrix composites show a number of desirable features [3-5], the most important of which are: relatively high mechanical strength versus density, increased creep strength, higher modulus of elasticity and also increased resistance to wear.

Moulds and dies have traditionally been produced by material removal processes like milling, boring, cutting, grinding and polishing. The machining of composites is connected with several difficulties [6, 7]. The basic difficulty stems from hard particles included in the matrix constituting the reinforcing phase of the composite. They cause intensive abrasive wear of machining tools, even those which are made of cemented carbides. One of the more promising methods of machining of composite dies is electro-discharge machining EDM or wire electro-discharge machining WEDM [8, 9]. The choice of a proper material removal process for die making is, among others, dictated by issues of surface and sub-surface quality. For instance, a die with micro cracks or high residual stresses at the surface can have a ten times shorter life time than when the surface is well finished. The WEDM method allows us to obtain good surface and sub-surface properties [10].

The problems in wire cutting machining are the relatively slow cutting speed, the formation of a white layer and wire breakage. In this experiment, we tried to find the most important EDM process parameters for the machining of modified H13 steel and their composites with TiC particles. For comparison, conventional H13 steel without reinforcement was also carried out. The parameters we employed here were the pulse duration and load voltage. Their variations in cutting speed, surface roughness and metal removal rate were investigated.

EXPERIMENTAL CONDITIONS

Workpiece material

The materials used in this study were modified H13 (MH13) matrix composites containing 10, 20 and 30 vol.% TiC particles with an average diameter of 6 μm. Such composites were manufactured by the powder metallurgy method including hot isostatic pressing [3, 11].

The nominal and analyzed compositions of MH13 as well as their sizes and size distributions are presented in Tables 1 and 2.

TABLE 1. **Nominal composition of modified H13 tool steel powder [wt.%]**
TABELA 1. **Skład stali H13 po modyfikacji [% mas.]**

Element	C	Mo	Cr	Ni	Fe
Nominal	0.40	4.00	5.00	0.5	Rem.
Analyzed	0.43	4.38	5.46	0.672	Bal.

TABLE 2. **Size and size distribution of modified H13 powder [μm]**
TABELA 2. **Rozkład ziarnowy proszku H13 [μm]**

Nominal	Analyzed		
	D10	D50	D90
<100 μm	12.23	41.5	103.17

The atomized matrix powder was mixed with a TiC powder using a Tubular mixer for 60 min.

The mixed materials were consolidated using Hot Isostatic Pressing (HIP). Prior to the HIP process, the powder materials were placed in a steel can. The conditions of hot isostatic pressing for the modified H13 tool steel matrix composites were: temperature 1150°C, time 4 hours and pressure 100 MPa.

Cutting procedure

WEDM cutting was conducted by Adex BV (Venlo, The Netherlands) using a Fanuc Robcut α-1B machine equipped with a RC (resistance-capacitance) type relaxation generator. The dielectric used in this experiment was deionized water [12]. The tool material used was Superbrass 900 with a diameter of 0.25 mm. The nominal composition of the wire is as follows: 63% Cu and 37% Zn. The process parameters used are listed in Table 3.

TABLE 3. **WEDM parameters**
TABELA 3. **Parametry obróbki WEDM**

Tap	2	4	6	8	10
Load voltage	102 V	122 V	143 V	153 V	159 V
Pulse duration	0.5 μs	1 μs	1.5 μs	2 μs	2.5 μs

RESULTS AND DISCUSSION

General observation

In general, when the pulse duration is too low, there is almost no cut, and as a result, the cutting time is extremely long although the cut surface appears to be very smooth. Moreover, short circuiting occurs frequently. On the other hand, when the pulse duration is set very high, wire breakage often takes place. Because the heat brought to the workpiece is not homogenous, local oxidation takes place, resulting in color differences on the cut surface in the longitudinal direction. This phenomenon is observed in the materials of MH13 and also those with TiC reinforcement.

Workpiece removal rate

The workpiece removal rate (WRR) [mm^3/min] represents the amount of material removal per unit time and thus the machining speed. The effects of the pulse time and no load voltage on the material removal rate for MH13 and its composites are shown in Figures 1a and 1b.

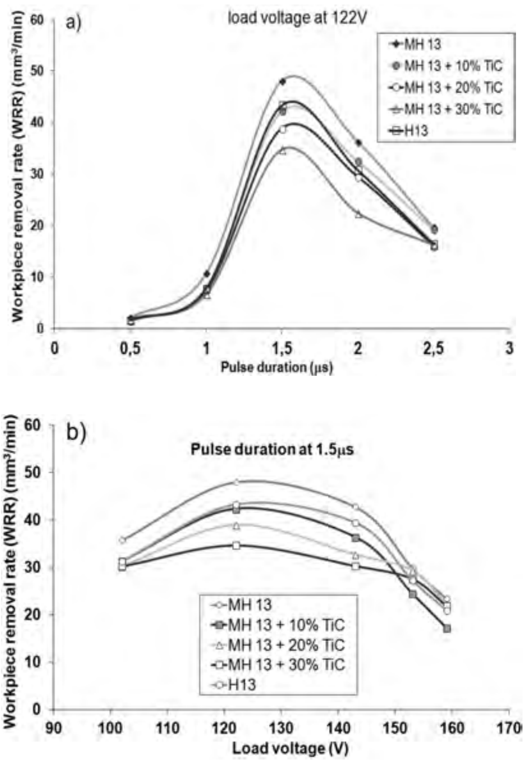

Fig. 1. Workpiece removal rate as function of: a) pulse duration and b) load voltage

Rys. 1. Wydajność obróbki w funkcji: a) czasu trwania impulsu, b) napięcia

WRR first increases with the pulse duration, then peaks at 1.5 µs, and finally goes down. Therefore an optimum pulse duration from the standpoint of machining rate exists. The same optimum WRR was obtained at load voltage at 122 V in Figure 1b. These results are as expected because WRR increases with increased discharge energy. With a short pulse duration and a low load voltage, the plasma channel in the dielectric is very small and therefore the material removal rate is low.

With an increasing amount of reinforcement, the WRR decreases. This can be explained by a number of facts. Firstly, the electrical conductivity of the modified H13 tool steel decreases due to the addition of the ceramic reinforcement. Furthermore, because of the low thermal conductivity and much higher thermal resistance of TiC, the ceramic particles shield and protect the tool steel matrix from vaporising and so the removal rate decreases. It was observed that the TiC particles were not melted during the machining process. Furthermore it was rare to find broken pieces of the ceramic particles deposited on the machined surface. The breakage of a TiC particle probably occurs because of thermal shock, or prior damage during manufacturing. The removal of the MMC occurs through melting and vaporising the matrix material surrounding the ceramic particle and at some points the entire particle becomes detached from the matrix. The exposure of entire TiC particles during machining provides the conditions for arcing to occur, which makes good flushing conditions essential. If the flushing is inadequate, the TiC grains trap sufficient molten MH13 on the surface to build a conductive path between the electrodes, which causes abnormal arcing. Therefore efficient flushing is very important for the successful machining of particle reinforced MMC when using EDM.

Surface topography

The working surface has an irregular structure, caused by the nature of the electrical discharge occurring in the gap between the electrodes. It can be seen that the surface of the MMCs contains smooth craters. Figure 2 shows the surface topography of the MH13 composites after the WEDM process. As expected, the crater size increases with increasing pulse duration (and load voltage), which has a greater input energy, and hence, more deep holes are formed, and thus the surface is rougher.

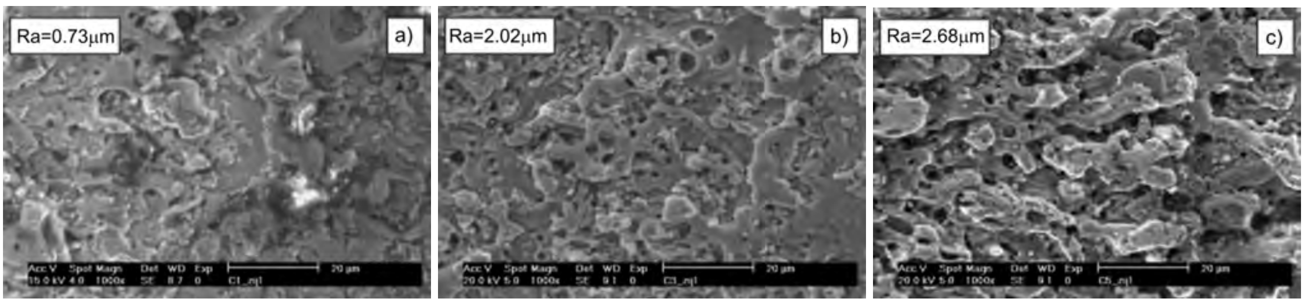

Fig. 2. SEM micrograghs of working surfaces of MH13 with 20 vol.% TiC reinforcement, pulse duration and load voltage are: a) 0.5 µs, 122 V; b) 1.5 µs, 122V; c) 2.5 µs, 122V

Rys. 2. Mikrografia SEM powierzchni stali MH13 z 20% obj. TiC; czas trwania impulsu i napięcie wynoszą: a) 0,5 µs, 122 V; b) 1,5 µs, 122 V; c) 2,5 µs, 122 V

Surface roughness

From Figure 2, we can see that the average roughness *Ra* of the machined surfaces of MH13 and composites with a TiC increase with both pulse duration and load voltage. The average roughness shows a less steep variation with load voltage (Fig. 2b) than with pulse duration (Fig. 2a). This means that the roughness is less dependent on load voltage than on pulse duration.

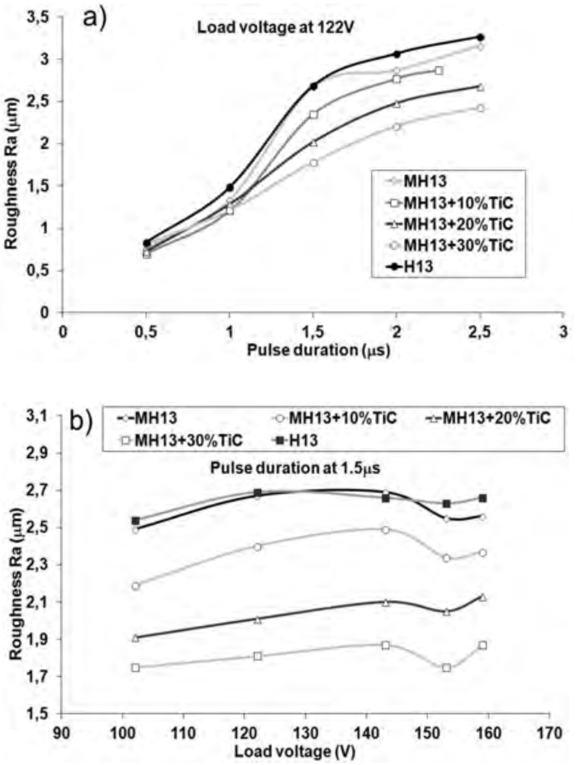

Fig. 3. Surface roughness *Ra* as function of: a) pulse duration b) load voltage

Rys. 3. Chropowatość powierzchni *Ra* w funkcji: a) czasu trwania impulsu, b) napięcia

With an increasing amount of TiC reinforcement, the surface roughness is also reduced, because the TiC particles are deposited along the inner surface of the workpiece and may act as a mechanical polishing medium in the EDM process. That is the reason why the surface roughness decreases when we increase the TiC content.

The graphs in Figure 3 also show that conventional H13 has rougher surfaces than MH13 when pulse duration is a variable, although the difference is very small. When load voltage is a variable, the surface roughness of H13 and MH13 intersect, there is almost no significant difference between them.

CONCLUSIONS

Based on the results obtained from the WEDM cutting of H13 steel, MH13 powder metal steel and composites based on MH13, the following conclusions can be drawn.

- The roughness of the WEDM cut surface increases with pulse duration. However, it does not go straight up with load voltage. There is a roughness peak where the load voltage is at 143 V. H13 has a rougher machined surface than MH13.
- The surface of MH13 is rougher than its composites with TiC particles. The more reinforcement, the smoother the surface.
- The workpiece removal rate rises with pulse duration. After reaching a peak, it falls. The peak value of the working speed is when the pulse on-time is at 1.5 μs. The same concerns the load voltage. A peak value exists, which is at 122 V.
- The cutting rate of H13 is lower than that of MH13.
- With an increase in TiC, the cutting becomes slower and the workpiece removal rate is lower, no matter which parameter is chosen, pulse on-time or no load voltage.
- The recommended conditions are:

Materials	On-time [μs]	Off-time [μs]	Load voltage [V]	Average roughness [μm]	Cutting rate [mm^3/min]
H13	1.5	10	122	2.69	43.33
MH13+0% TiC	1.5	10	122	2.67	48.01
MH13+10% TiC	1.5	10	122	2.35	42.21
MH13+20% TiC	1.5	10	122	2.02	38.83
MH13+30% TiC	1.5	10	122	1.78	34.76

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