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Investigation of Machinability of Aluminum (Al1070) Matrix, Silicon Carbide (SiC) and Boron Carbide (B4C) Reinforced Hybrid Composite Materials

Alüminyum (Al1070) Matris, Silisyum Karbür (SiC) ve Bor Karbür (B4C) Takviyeli Hibrit Kompozit Malzemelerin İşlenebilirliğinin İncelenmesi

Yunus Kartal[1*], Ali Osman Er[1]

[1]*Kırıkkale University, Faculty of Engineering and Natural Science, 71450, Kırıkkale, Turkey*

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Abstract

In this study, the machinability of hybrid metal matrix composite (MMC) materials were investigated. Experiments were carried out on a CNC lathe using aluminium 1070 matrix SiC and B_4C reinforced MMC materials without cooling fluid. The effect of cutting parameters and MMC reinforcement ratios on machinability has been examined. It has been tried to determine the optimum reinforcement ratio and cutting parameters in the machining process of hybrid reinforced MMC materials. As a result of this study, it was tried to contribute to the industrial area by determining the most suitable cutting parameters for Al1070 matrix SiC and B_4C hybrid reinforced MMC materials.

Key Words

Hybrid MMC, Machinability, Hardness, Cutting force, Roughness, Turning.

Öz

Bu çalışmada hibrit metal matrisli kompozit (MMK) malzemelerin işlenebilirliği incelenmiştir. Çalışma kesme sıvısının kullanılmadığı atmosferde gerçekleştirilmiş ve alüminyum 1070 matris SiC ve B_4C takviyeli MMC malzemeleri kullanılarak, CNC tornalama tezgahında gerçekleştirilmiştir. Takviye oranı ve işleme parametrelerinin etkisi incelenmiştir. Hibrit takviyeli MMK malzemelerin talaşlı imalat sürecinde optimum takviye oranı ve kesme parametreleri belirlenmeye çalışılmıştır. Bu çalışma sonucunda Al1070 matrisli SiC ve B_4C hybrid takviyeli MMK malzemeleri için en uygun kesme parametreleri belirlenerek endüstriyel alana katkı sağlanmaya çalışılmıştır.

Anahtar Kelimeler

Hibrit MMK, İşlenebilirlik, Sertlik, Kesme kuvveti, Pürüzlülük, Tornalama.

***Responsible Author:** *y.kartal@kku.edu.tr*

1. Introduciton

The developments in technology have made it possible new materials to emerge. One of these new materials produced are composite materials. Composite materials are made by combining at least two traditional materials. The machinability of composite materials has been studied by many researchers in the literature until this time. The studies about composite materials can be summarised as follows. Davim J. P., (2003). investigated the effects of cutting speed, feed rate and machining time on aluminium matrix SiC reinforced MMC materials. It has been determined that cutting speed is the most effective parameter on tool wear. Also, It was determined that the feed rate is the most important parameter affecting surface roughness, followed by the cutting speed. Kılıçkap E., (2005). investigated tool wear and surface roughness after turning MMC material with 5% SiC reinforcement volume ratio. It is stated that the most effective factors causing tool wear is the cutting speed. It has been determined that higher cutting speeds and lower feed speeds reduce surface roughness. Bahçeci E., (2006). examined the impact of reinforcement ratio and production characteristics on the machinability properties of MMC materials. Machining properties of MMC material were evaluated in terms of chip root, cutting force, surface roughness and chip types. The machining tests were carried out by using PCD coated cutting tool. At the end of the study, it was determined that excessive shear chips were formed at the cutting edge and therefore, the MMC material had a bad surface quality. Palanikumar K., (2007). investigated the effect of cutting conditions on the surface roughness. The work was carried out using a tungsten carbide tool on the lathe. At the end of the study, it was determined that the most effective parameter affecting the surface roughness was the feedrate and then the rate of reinforcement. Sur G., (2008). investigated the machinability of MMC materials. Tungsten carbide (WC) and cubic boron nitride (CBN) cutting tools were used. At the end of the study, it was determined that the properties of the reinforcement element affected the wear of the cutting tools and the change of force components. Ozben T., (2008). investigated the properties of SiC reinforced MMC materials. At the end of the study, it was determined that the increase in the volume ratio in the MMC material increased the rise of tool wear. And surface roughness. It was determined that feed rate increases surface roughness while cutting speed decreases. Pramanik A., (2008). investigated the effect of reinforcing elements on the machinability properties of MMC materials. It has been determined that during the process, the stress levels on the surface of the MMC materials are increased. Also it has been determined that increased reinforcement ratio has facilitated chip breaking. Günay M., (2009). investigated the properties of Al231 matrix SiC reinforced metal matrix composites. In the study, it was determined that increasing the cutting speed reduces the surface roughness. And that this was caused by wear on the nose region of the tool. Increasing the SiC weight ratio in the MMC material increases the cutting forces. Sahoo A. K., (2013). investigated the effects of processing parameters (cutting speed, feed rate, depth of cut) on machinability in Al matrix SiC reinforced MMC materials. BUE formation was observed in the cutting tool, and the abrasive and adhesive tool wear mechanisms were determined in the cutting tool. Suresh P., (2014). investigated the machinability properties of Al-SiC-Gr hybrid composite materials. In the study, hybrid MMC material was used at different reinforcement volume ratios (5%, 7%, 10%). At the end of the study, the machinability properties of hybrid composite materials with 10% reinforced volume ratio, which is the highest reinforced volume ratio, were found to be better than the others. Rui-song vd., (2016). investigated tool wear, surface quality and chip shape in TiB2-reinforced Al matrix MMC material. Their results showed that; in case of using PCD tool in the machining of TiB2/Al MMC materials; PCD tool had shown beter wear resistance and high surface quality. It was noticed that the main mechanism of wear was in the form of abrasive and adhesive followed by diffusion and oxidation wear. Also it was stated that the surface quality was better than SiC / Al MMC materials and there was no groove or hole on the surface. The reason for the better surface quality compared to SiC/Al MMC materials is the small reinforcement size and a better reinforcement/matrix interface adhesion.. The chip shape was similar to the aluminum material without reinforcement on the macro scale but similar to the SiC / Al MMC material on the micro scale. Srivathsan et al. (2017). a study on turning of Al6061 matrix with 10% B4C reinforced MMC.The MMC produced by the stir casting method. Experiments were performed using PCD cutting tool with different parameter values and in the experiments, energy consumption, surface quality and tool wear had been studied. It was stated that the surface quality and energy consumption were higher at high cutting speeds and the reason of tool wear was mainly due to hard reinforcing elements in MMC material construction. Jinfeng L,. vd., (2009). had investigated the effect of graphite particles on machinability in SiC / Gr / Al MMC materials. It was determined that the increase of the graphite particle size slightly changes the tool wear but significantly reduces the cutting force. Also It was determined that the cutting force was higher than that of SiC / Al materials. The characteristic of graphite particles affected tool wear and shear force. Hiremath V vd., (2016). investigated the effect of machining parameters on cutting force and surface roughness in aluminum matrix MMC materials. Experimental studies were carried out with 0, 5, 7, 9% B_4C reinforced MMC materials and the changes in cutting force and roughness in MMC materials were determined during turning. It had been found that as the B_4C reinforcement at different ratios in the study increased, the cutting force decreased. This decrease in cutting force was thought to be caused by increment in the porosity, hardness and dislocation density. When the SEM image was examined, it was seen that BUE was formed at low cutting speed and high cutting depth values in 5% reinforced MMC material. As cutting speed increased, surface quality improved significantly but decreased with increasing feed and cutting depth. Siddesh Kumar N.G. vd., (2017). investigated the effect of feed rate and depth of cut on surface roughness and cutting forces in nano-hybrid MMC materials. MMC materials were produced by the mixed casting method. With increasing feed and reinforcement ratio, it was determined that surface roughness and cutting forces increased but decreased with increasing cutting speed. A mixture of plastic deformation and wear marks was observed on machined surface. At low cutting force, BUE formation is observed. Nas E. vd., (2015). investigated the effect of processing parameters on surface roughness in MMC materials. In the experiments, a matrix was designed based on full factorial design and average surface roughness. The lowest surface roughness value was obtained in the material reinforced with 7% graphite by weight. MMC material while the highest surface roughness value was obtained in the absence of graphite powder. It had been determined that the most important factor affecting the average surface roughness was the type of MMC material, the second most important factor was the feed rate and the cutting speed had the lowest effect. It was shown that the most effective factor on BUE formation was MMC material type, the second most important factor was the cutting speed and the lowest effective factor was the feed rate. Muguthu J.N. vd., (2013). investigated the effects of cutting speed, feed rate, cut of depth, and cutting tool on surface roughness, tool wear, and energy consumption when machining MMC materials. In the study, it was determined that the cutting parameters giving the best surface quality were obtained using the PCD tool with the average cutting speed (60m / min), the lowest feed (0.1mm / dev), the lowest cutting depth (0.1mm). In addition, the best parameters for the specific energy consumption were obtained using the PCD tool with the lowest cutting speed (40m / min), the average feed (0.15mm / rev), and the highest cutting depth (0.2mm). It was found that the most important effect on surface roughness is tool geometry and cutting speed is of secondary importance. It was determined that the most effective parameter on specific energy consumption was tool geometry, followed by feed rate. Channabasavaraja H.K. vd., (2016). investigated the effect of cutting speed, depth of cut and feed rate parameters on machinability in Al matrix B_4C reinforced MMC materials. Each parameter has been changed in 3 steps. MMC material was used at 3 different reinforcement ratios (0, 4, 8). It has been observed that the hardness of the MMC material increases with the increase of the reinforcing ratio of the MMC material. Furthermore, the cutting forces increased with the increase of the reinforcement ratio.

When the studies are examined, it is understood that there is a lack of studies on the machinability of hybrid MMC materials. In this study, two different ceramic reinforcements were used due to the lack of ceramic additives to the same matrix at different ratios in the literature, and the effect of these additives on the machinability of hybrid MMC materials by investigating the effect of cutting speed and feed rate on the machinability of hybrid MMC materials was tried to eliminate the deficiencies in the machinability of hybrid MMC materials and it was aimed to create a guide study on the machinability of hybrid MMC materials.

2. Materials and Methods

In the study, MMC materials were produced first then the experiments were conducted and the cutting forces and surface roughness were measured and evaluated in terms of performance of MMC materials.

2.1. Producing of MMC Materials

Electric resistive melting furnace was utilized for MMC material production. The matrix material was melted in the electric resistance melting furnace and the reinforcement material was mixed into the melt. After the mixing process was completed, the MMC materials in the molten state were poured into the sand mold and the MMC material was cooled in the room conditions. Then surface cleaning was performed on the universal lathe. In the study, silicon carbide (SiC) and boron carbide (B_4C) were used together in different ratios as reinforcing materials. The reason for using different proportions of reinforcement materials is to contribute to the studies in the literature in this application area.

SEM images taken from 5% SiC- 5% B_4C reinforced MMC materials are given in Figure 1. When the void structures in the in Figure 1a are examined, it is understood that the voids are caused by the falling B_4C structures, and in the view Figure 1b, the SiC particles are determined by the EDS analysis performed.

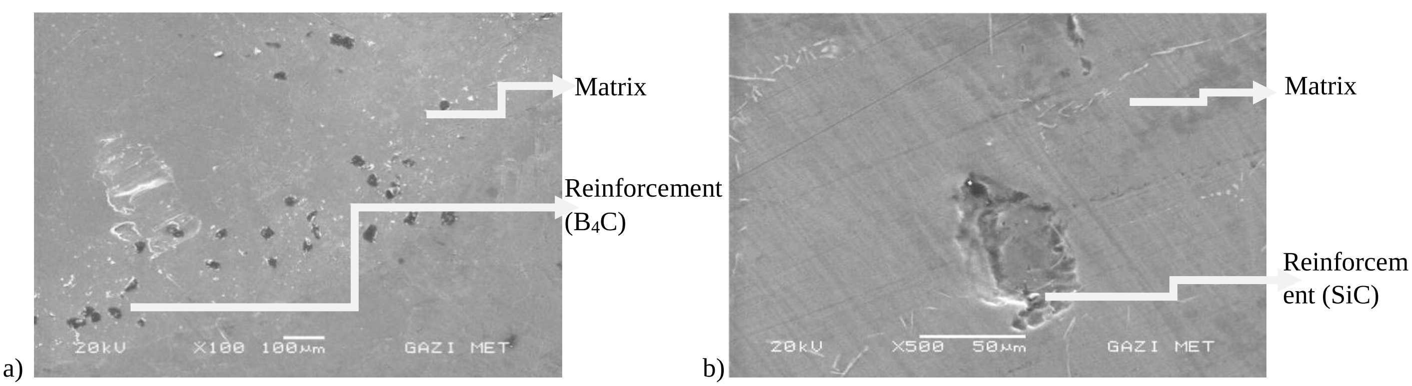

Figure1: Images of MMC materials reinforced with 5% SiC- 5% B_4C in SEM

2.2. Conducting Experiments

In the experiments, tool holder with code number DSBNR 2020K 12 was used as cutting tool holder. In machinability tests, inserts with chemical vapor deposition (CVD) TiN coated tungsten carbide material were used. The reason why the study was carried out with a CVD coated hard metal cutter: CVD techniques are the oldest vapor phase coating technique in industrial application and CVD coating is applied to reduce tool wear on hard metal inserts. The shape of the insert is given in Figure 2.

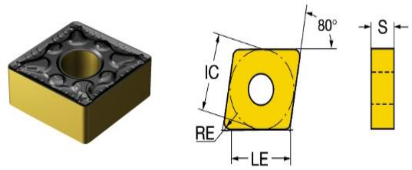

Figure 2: Insert shape

Al matrix SiC and B_4C reinforced hybrid MMC materials produced in two different reinforcement volume ratios were used to determine the machinability properties of MMC materials. The tests were carried out under dry cutting conditions, at computer numerical control (CNC) lathe, at three different cutting speeds, three different feed rate and constant cutting depth. In Table 3, the turning parameters and their values are given.

Table 3: Parameters and level.

Cutting depth (ap), mm	Feed rate (f), mm / rev	Cutting speed (V_c), m / min
0.5	0.05-0.1-0.15	100-200-300

2.3. Measurement of the Cutting Force and Surface Roughness

Cutting forces were measured in machining experiments using KISTLER 9257b dynamometer. HOMMEL TESTER brand T1000 surface roughness was used in machining experiments

3. Discussion

An important part of this work was created with measured cutting force data. At three different cutting speeds and three different feed rate values, cutting force data were measured by the dynamometer. The obtained data were recorded and archived immediately.

3.1. Cutting Forces

The effects of the machining parameters and reinforcement ratio on the cutting force were investigated. Figure 3 shows that the cutting forces measured by the dynamometer at three different cutting speeds and constant feed rate (0.1 mm/rev).

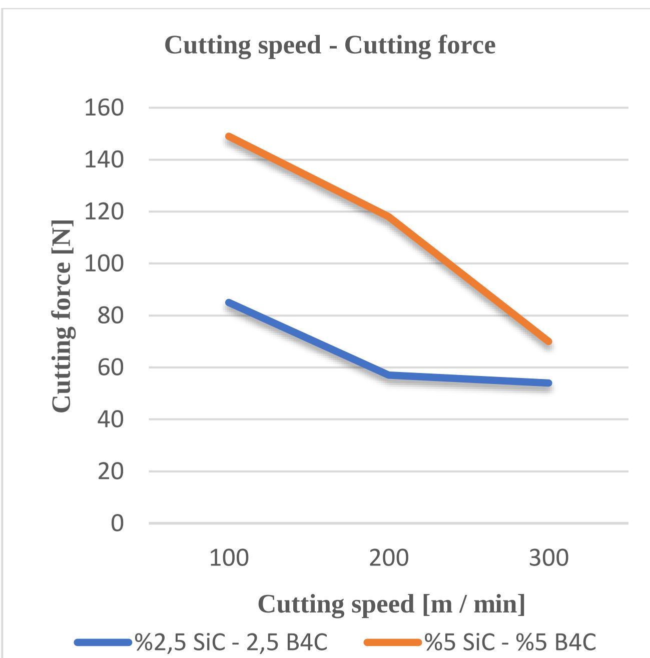

Figure 3: The variation of cutting force with cutting speed (f: 0.1mm/rev).

The effect of increasing cutting speed on cutting force at different reinforcement ratios is given in Figure 3. In MMC with different reinforcement ratios, the effect of cutting speed on cutting force is similar, and cutting force decreased with increasing cutting speed.

This decrease was 55% in MMC with %5 SiC-%5 B_4C reinforcements and 33% in MMC with reinforcements %2.5 SiC-%2.5 B_4C.It is thought that this decreasing is due to the rise in temperature in the cutting zone. At all cutting speeds, the cutting force measured at the reinforcement ratio %5 SiC-%5 B_4C were high. In this case, it is thought that in the MMC with %5 SiC-%5 B_4C reinforcement rates, the cutting tool is more straining with the reinforcement element.

Figure 4 shows the cutting forces measured by dynamometer at three different feed rates. The effect of increasing feed rate on cutting force at different reinforcement ratios is given in Figure 4. The cutting force of all MMC materials increased with increasing feed rate. It is thought that this increase is due to the growth of the cross sectional area of chip cutting area.

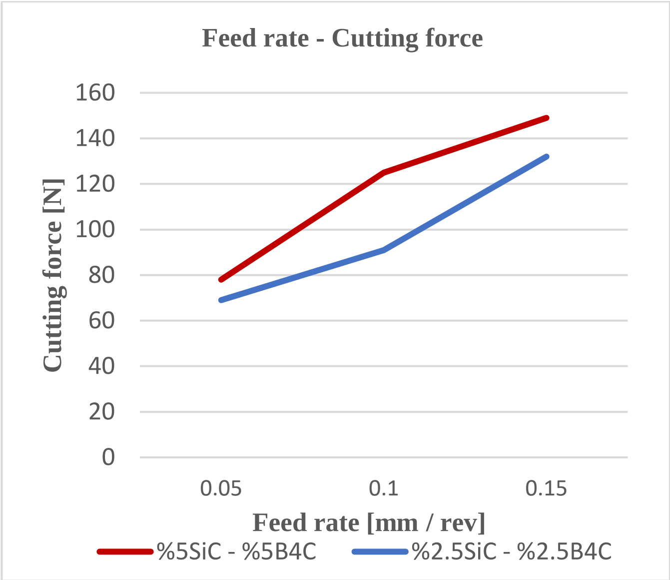

Figure 4: The variation of cutting force with feed rate (V_c: 300m/min)

Investigating the effect of reinforcement ratio on machinability in hybrid MMC materials is one of the important aims of the study. Figure 5 and Figure 6 shows the effect of the reinforcement ratio on the cutting force in hybrid MMC materials. The progression in each of the graphs are plotted as a result of the data obtained from the experiments, cutting speed is constant (300 m/min)in Figure 5 and also feed rate is constant (0.1 mm/rev) in Figure 6.

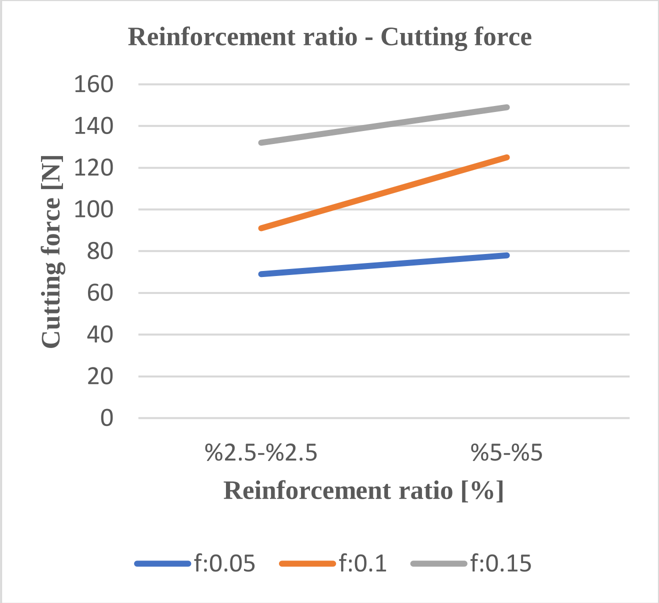

Figure 5: The variation of cutting force with reinforcement ratio (V_c: 300m/min)

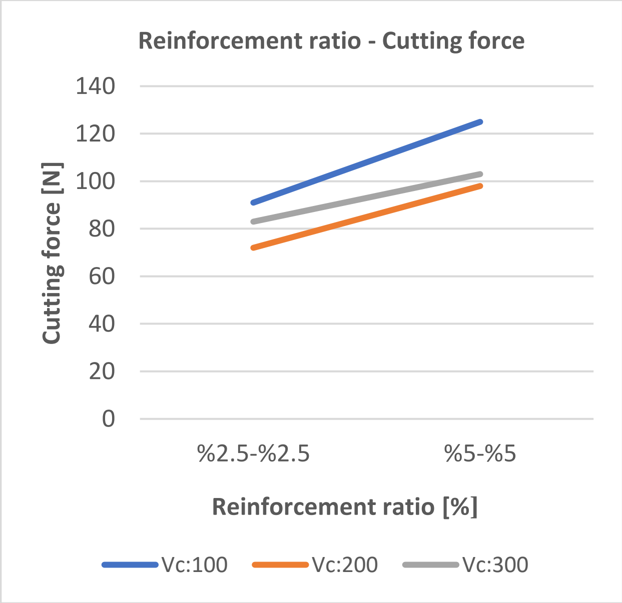

Figure 6: The variation of cutting force with reinforcement ratio (f :0.1mm/rev)

It was determined that the cutting force data value increases as the reinforcement volume ratio increases. The reason for this is the increased contact of the cutting tool with hard particles at high reinforcement volume ratios.

3.2. Surface Roughness

In MMC materials with two different reinforcement volume ratios, the surface roughness data obtained at 3 different cutting speeds and constant (f= 0.1 mm / rev) feed rate are shown graphically in Figure.7.

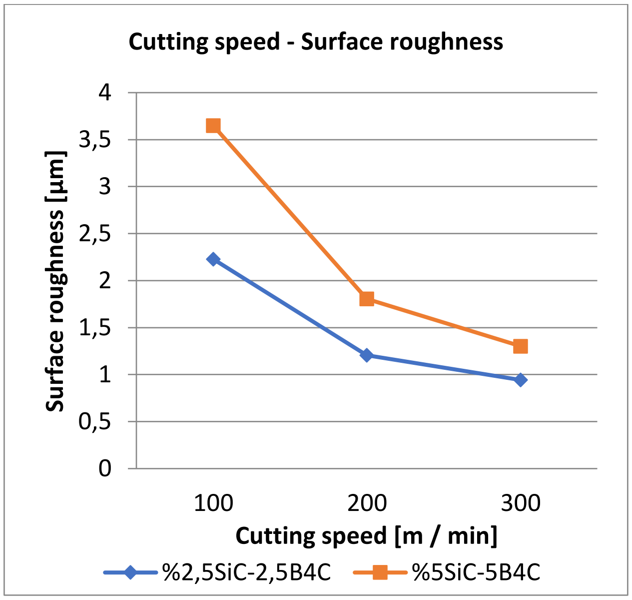

Figure 7: The variation of surface roughness with cutting speed (f:0.1 mm/rev)

As can be seen in Figure 7, the progression of the movement has generally caused similar behavior for the whole reinforcement volume ratio. By increasing the cutting speed, the surface roughness data are reduced in all reinforcement ratio materials. Figure 8 shows the measured values of the surface roughness at different feed rate values.

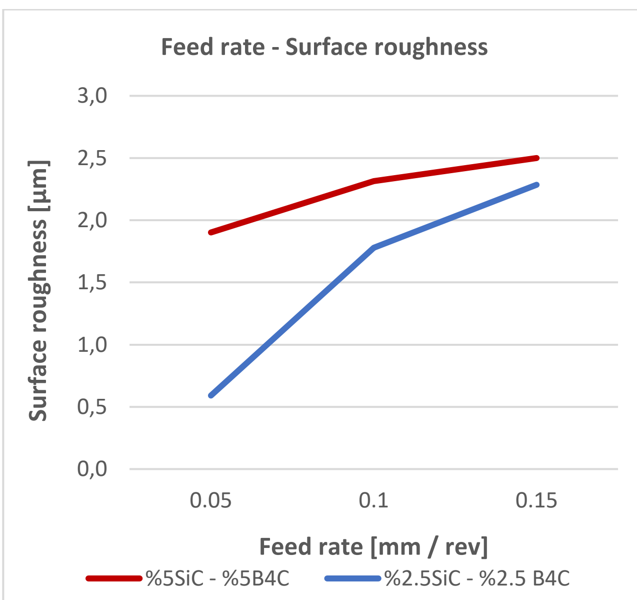

Figure 8: The variation of surface roughness with feed rate (V_c:100m/min)

Figure 8 shows effect of the feed rate on the surface roughness. At all reinforcement ratios, surface roughness values increased with feed rate.

One of the objectives of this study is to examine the impact of reinforcement ratio on machinability in MMC materials. Figure 9 and Figure 10 shows the effect of the reinforcement ratio on the surface roughness of hybrid MMC materials The progression in each of the graphs plotted as a result of the data obtained from the experimental work, feed rate is constant and 0.1 mm / rev in Figure 9 and cutting speed is constant and 100 m/min in Figure 10.

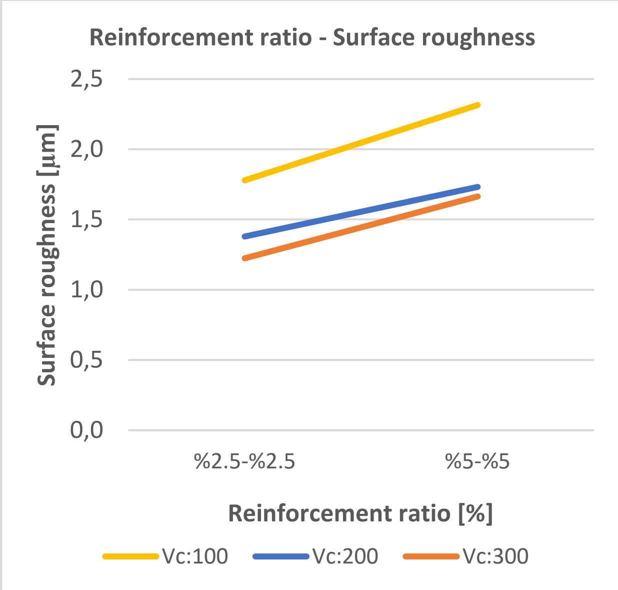

Figure 9: The variation of surface roughness with reinforcement ratio (f:0.1 mm/rev)

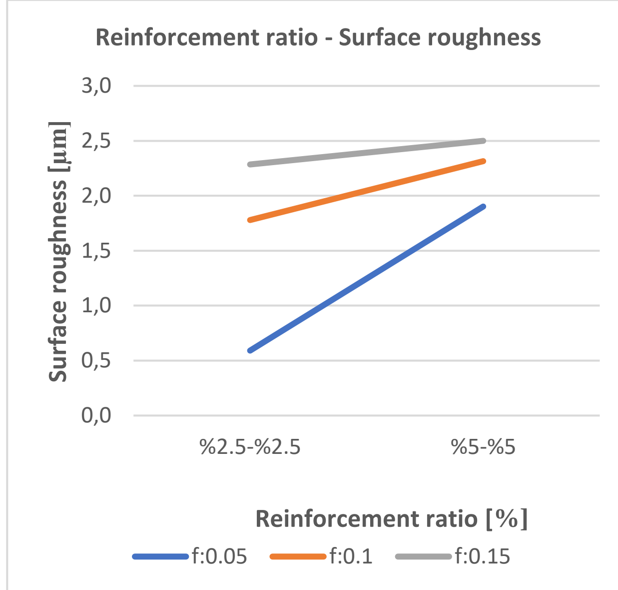

Figure 10: The variation of surface roughness with reinforcement ratio (V_c:100 m/min)

Surface roughness increases with increasing reinforcement ratio. The reason for this can be the increase of the hard particles in ascending reinforcement rates which causes more machine vibration.

3.3. Hardness

The hardness data obtained in MMC materials with two different reinforcement volume ratios are shown in Figure 11. The hardness values obtained are in Vickers. A force of 1000 grams of force was applied to measure the hardness values of the materials.

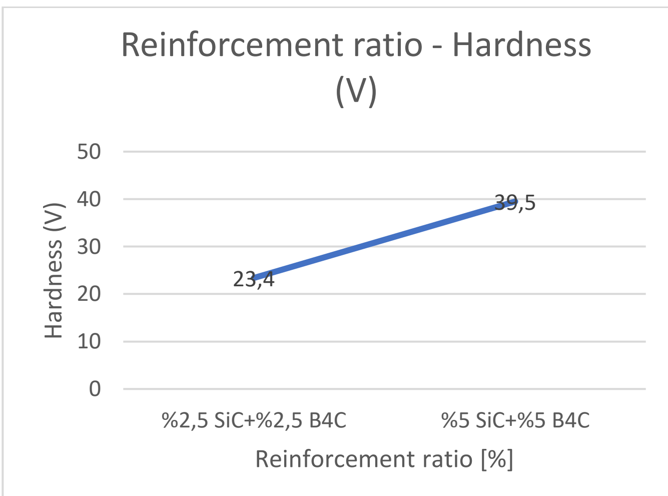

Figure 11. The variation of hardness with reinforcement ratio (Load:1000 gf)

As shown in Figure 11, the hardness value increased with the increase in the reinforcement ratio. This situation is an expected result. With the increase in the reinforcement ratio, the hardness value increased due to the increase of hard particles in the composite material.

4. Conclusion

• The machinability properties of Al matrix, SiC and B_4C reinforced hybrid MMC materials produced by the mixed casting method are evaluated in terms of the basic machinability criterion, cutting force and surface roughness. The results of the machinability properties of the MMC samples produced are summarized as follows:

• As the cutting speed increases, the cutting force decreases, which are related with the temperature, increase in the cutting zone. There is not any well-proportional relationship between the variation of reinforcement ratios and forces.

• The cutting force increased with increase of the feed rate, which is due to the increase in cross sectional area of the material in the cutting zone.

• As the reinforcement ratio increased from 5% to 10%, there was an increase in cutting force with increasing cutting speed.

•Surface roughness values generally decreased with increasing cutting speed. The reason for this can be the increase of temperature value in the cutting zone parallel to the increasing cutting speed.

• All MMC materials have increased surface roughness with increasing feed rate value.

• The surface roughness value has increased with the increase of the reinforcement ratio. The reason for this is that there is more reinforcement material on the surface at high reinforcement volume ratios.

• The measured hardness data behaved similarly to the measured shear force data. With the increase of the reinforcement rate, both shear force and hardness value data increased. This is actually an expected result. It is thought that the mechanism that causes this situation is the increasing rate of reinforcement.

• In future studies that will examine the processability of metal matrix composites, researchers can examine the mechanical properties, internal structure and conductivity of composites produced by different production methods.

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