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Experimental Investigation of Machinability of Filler Weld Applied to DIN 1.2379 Tool Steel by Milling Method

Yusuf SİYAMBAŞ[1*]

[1]*Erzincan Binali Yıldırım University Vocational High School, Department of Machinery and Metal Technologies, Erzincan, Turkey*

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Anahtar Kelimeler

Dolgu kaynağı
Kesme kuvveti
Yüzey pürüzlülüğü
Regresyon analizi

Graphical/Tabular Abstract (Grafik Özet)

In this study, DIN 1.2379 cold work tool steel materials were subjected to filler welding with welded joining process and their machinability was investigated. / Bu çalışmada, DIN 1.2379 soğuk iş takım çeliği malzemelere kaynaklı birleştirme işlemi ile dolgu kaynak işlemi yapılmış ve işlenebilirliği araştırılmıştır.

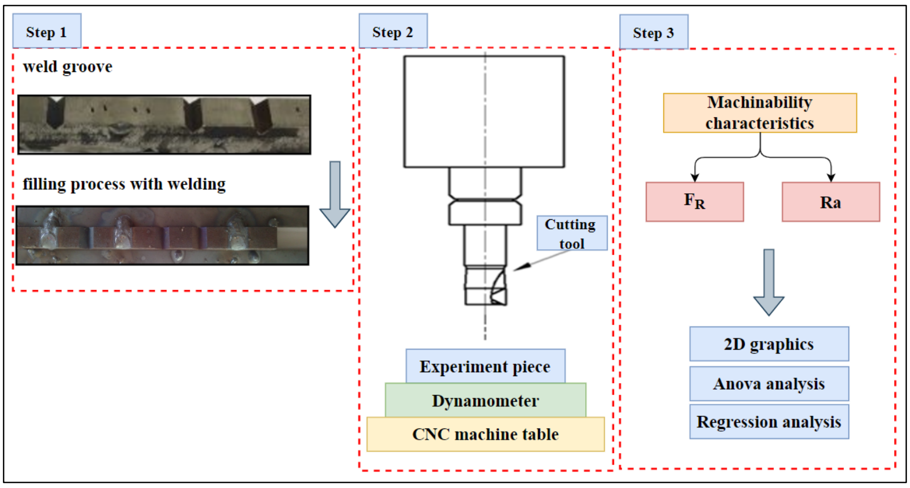

***Figure A:** Stages of the experimental study / **Şekil A:** Deneysel çalışmanın aşamaları*

Highlights (Önemli noktalar)

- *Machinability of filler weld applied to DIN 1.2379 cold work tool steel. / DIN 1.2379 soğuk iş takım çeliğine uygulanan dolgu kaynağının işlenebilirliği.*
- *Effects of cutting parameters on machinability characteristics. / Kesme parametrelerinin işlenebilirlik karakteristikleri üzerindeki etkileri.*
- *Statistical data with ANOVA and regression analysis. / Anova ve regresyon analizi ile istatistiksel veriler.*

***Aim (Amaç):** In this study, it was aimed to investigate the milling of filler welds applied to DIN 1.2379 cold work tool steel in terms of cutting force and surface roughness. / Bu çalışmada DIN 1.2379 soğuk iş takım çeliğine uygulanan dolgu kaynaklarının frezelenmesinde kesme kuvveti ve yüzey pürüzlülüğü açısından araştırılması amaçlanmıştır.*

***Originality (Özgünlük):** It has been observed that the studies on filler welding of DIN 1.2379 steel are very limited and the machinability characteristics have not been investigated experimentally and statistically together. / DIN 1.2379 çeliğinin dolgu kaynağı üzerine yapılan çalışmaların oldukça sınırlı olduğu ve işlenebilirlik karakteristiklerinin deneysel ve istatistiksel olarak bir arada araştırılmadığı gözlemlenmiştir.*

***Results (Bulgular):** As a result of the experiments, Ra values ranged between 0.100 µm and 0.226 µm, while F_R values ranged between 399 N and 857 N. It was found that feed rate had the greatest impact on both cutting force and surface roughness. / Deneyler sonucunda Ra değeri 0.100 µm ile 0.226 µm değerleri arasında değişirken, F_R değerleri 399 N ile 857 N arasında oluşmuştur. Kesme kuvveti ve yüzey pürüzlülüğü üzerinde en etkili parametrenin ilerleme oranı olduğu belirlenmiştir.*

***Conclusion (Sonuç):** The R^2 values obtained for F_R and Ra showed that the mathematical models developed to predict the machining outputs can be used with high reliability for milling the filler weld applied to DIN 1.2379 material. / F_R ve Ra için elde edilen R^2 değerleri, işleme çıktılarını tahmin etmek için geliştirilen matematiksel modellerin DIN 1.2379 malzemeye uygulanan dolgu kaynağının frezelenmesi için yüksek güvenilirlikle kullanılabileceğini göstermiştir.*

*Corresponding author, e-mail: yusuf.siyambas@erzincan.edu.tr
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Abstract

Multi-purpose designed and manufactured constructions may also wear out over time, and breakage or rupture may occur as a result of this wear. In terms of cost, it is more economical to produce these parts by the welded joining method instead of reproducing them. In this context, in this study, a filler welding process was performed on DIN 1.2379 cold work tool steel materials with a welded joining process. The surfaces formed as a result of the filling process were machined by the milling method on a CNC milling machine. The investigation revealed that when cutting speed increased, surface roughness levels reduced. The opposite was observed for the cutting forces with increasing cutting speed. As a result of the experiments, Ra values ranged between 0.100 µm and 0.226 µm, while F_R values ranged between 399 N and 857 N. It was found that feed rate had the greatest impact on both cutting force and surface roughness. Regression analysis was used to create prediction equations for surface roughness and cutting force, and the outcomes of the experiments and predictions were compared.

DIN 1.2379 Takım Çeliğine Uygulanan Dolgu Kaynağının Frezeleme Yöntemi ile İşlenebilirliğinin Deneysel Araştırılması

Makale Bilgisi

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Öz

Çok amaçlı tasarlanmış ve imal edilmiş konstrüksiyonlar da zamanla aşınmalar ve bu aşınmalar sonucu kırılmalar veya kopmalar oluşabilmektedir. Bu parçaların, maliyet açısından yeniden üretilmesi yerine kaynaklı birleştirme yöntemi ile üretilmesi daha ekonomik olmaktadır. Bu kapsamla bu çalışmada, DIN 1.2379 soğuk iş takım çeliği malzemelere kaynaklı birleştirme işlemi ile dolgu kaynak işlemi yapılmıştır. Dolgu işlemi sonucunda oluşan yüzeyler CNC freze tezgâhında frezeleme yöntemiyle işlenmiştir. Çalışma sonucunda, kesme hızının artışı ile yüzey pürüzlülük değerleri düşüş göstermiştir. Kesme kuvvetlerinde ise kesme hızı artışı ile tam tersi durum gözlemlenmiştir. Deneyler sonucunda Ra değeri 0.100 µm ile 0.226 µm değerleri arasında değişirken, F_R değerleri 399 N ile 857 N arasında oluşmuştur. Kesme kuvveti ve yüzey pürüzlülüğü üzerinde en etkili parametrenin ilerleme oranı olduğu belirlenmiştir. Regresyon analizi ile kesme kuvveti ve yüzey pürüzlülüğü için tahmin denklemleri geliştirilmiş olup deneysel ve tahmin sonuçları karşılaştırılmıştır.

1. INTRODUCTION (GİRİŞ)

Wear of parts as a result of metal-to-metal friction causes serious problems in mechanical systems. These problems lead to shortened component lifetimes and system failures. Parts need to be replaced or repaired to eliminate these problems and maintain the efficiency of the system. Repairing worn parts is much more economical than the high cost of buying new parts. Weld repairs are a common method used to repair damage to metal or other weldable materials. Filler welding is a welding process used to rebuild or strengthen the surfaces of worn or damaged metal parts [1]. This process is done to extend the life of parts exposed to excessive wear, impacts, or high temperatures. Filler welding is widely used, especially in sectors such as mining, cement, power generation, agriculture, and heavy industry [1]. There are many welding methods used in today's production. Gas metal arc welding, one of these methods, has an important place in hardfacing welding applications because it is easy to apply and allows high welding speeds [2]. This welding technique can be applied manually or integrated into automation systems, enabling bi-directional welding [3]. Gas metal arc welding is divided into

*Corresponding author, e-mail: yusuf.siyambas@erzincan.edu.tr
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metal active gas (MAG) and metal inert gas (MIG) according to the type of gas used. In MIG welding, noble gases such as argon and helium are used as shielding gases, while carbon dioxide or gas mixtures are used in MAG welding. The simplicity of application of MIG welding has made it a highly sought-after and popular welding technique for all non-ferrous metals and alloys. However, in order for the welded repaired part to be reused, the welded area must be restored to its original condition. In this case, secondary operations such as grinding, sanding, and machining are needed.

The term "machinability" describes a material's ease or difficulty of machining. It results in less energy consumption, reduced machining times, good surface quality, and low tool wear during chip removal in a material with high machinability. Machinability depends on the material properties as well as the machining method and machining parameters. Criteria like cutting force, surface quality, tool wear, energy consumption, and dimensional accuracy and tolerances are used to comprehensively assess the machinability of a material [4-7]. Studies investigating the machinability of filler welds have been conducted in the literature. In an experimental study, five layers of Hastelloy C type material with layer thickness ranging from 2-3 mm were deposited on the surface of a 60 mm thick 56NiCrMoV7 steel block using semi-automatic MIG welding. They used 80 m/min cutting speed, 0.12 mm axial depth of cut, 12 mm cutting width, and 0.05 mm feed rate as machining parameters. During the experiments, it was noted that the side surfaces of the cutting tools were worn due to the high hardness of the workpiece surface. It was reported that the machining of nickel-based hard surface layers is limited to high speed dry machining due to rapid tool wear [8]. In another experimental study, the weldability and machinability of austenitic stainless steels strengthened with high nitrogen content were investigated. The parts were filled by TIG welding at a rate of 26 g/min. The investigation led to the conclusion that 40 m/min should be the cutting speed and that low cutting speeds prolong tool life [9]. In another study, the worn area of X40CrMoV5-1 hot work tool steel was filled by electric arc welding, and the milling performance of different coated carbide inserts was investigated. Resultant force, surface roughness, and cutting power with respect to machining parameters were optimized by the Taguchi-based gray relational analysis method. As a result of the study, it was stated that the resultant force and surface roughness are affected by the feed rate and, the cutting speed is the most effective parameter for the cutting power [10]. In another study, the machinability of welded repaired DIN 1.2344 hot work tool steel was investigated with TiAlN-coated carbide tools. The machining parameters were determined as feed rate, cutting speed, and depth of cut. As a result of the experimental study, it was stated that the most effective parameter on surface roughness was chip depth, while all parameters were effective on cutting force. It is said that the most effective parameters in terms of cutting temperature are chip depth and speed [11]. In another experimental study, the cutting force generated in the milling process of modified AISI P20 steel was investigated using the response surface method. First and secondary prediction models of the cutting force were developed based on feed rate, cutting speed, axial depth of cut, and radial depth of cut. Feed rate was the most effective input parameter, followed by cutting speed, axial depth of cut, and radial depth of cut, according to Anova analysis [12]. In another study, the face-milling performance of hard-facing weld metal on JIS-S50C carbon steel was investigated on microstructure, chip characteristics, wear properties, and surface roughness. After comparing the wear of the cutting tool edge in wet and dry conditions, it was found that the dry condition exhibits a smaller flank wear than that of the wet condition. They explained the severe wear in the wet condition by the fact that a greater amount of coolant oil droplets cannot penetrate into the chip-tool interface and then provides an insufficient amount of lubricant in order to decrease the cutting temperature [13]. In another study, the machinability of hard surfaces deposited by nickel-based welding was investigated at high cutting speed. As a result of the study, it was stated that the high tool wear was caused by the 1 mm top layer of the hard surface coating leading to the formation of notches and chips on the cutting surface. It was reported that 190 m/min cutting speed is the most suitable value in terms of cutting forces. They also related the increase in power during milling to tool wear [14].

The literature research revealed that filler welding is often employed in repair processes. In addition to the economic advantages of the method, there are also disadvantages, such as tool wear during the processing of the hard structure caused by the weld structure. Within this context, the suitability of the processing parameters comes to the fore. This work examined surface roughness and cutting force during the milling of filler welds applied to DIN 1.2379 cold work tool steel.

2. MATERIAL AND METHOD (MATERYAL VE METOT)

The steps carried out for this experimental study are presented comprehensively in Figure 1. A Buğra MIG 650 SW brand welding machine was used for the welding process. Technical specifications of the welding machine are given in Table 1. SG2 Geka brand wire was used as gas metal arc welding wire (Table 2). The welding process was performed at 24 volts, 120 ampere welding current, and 3 m/min wire feed speed. Images of the welded and machined samples are given in Figure 2.

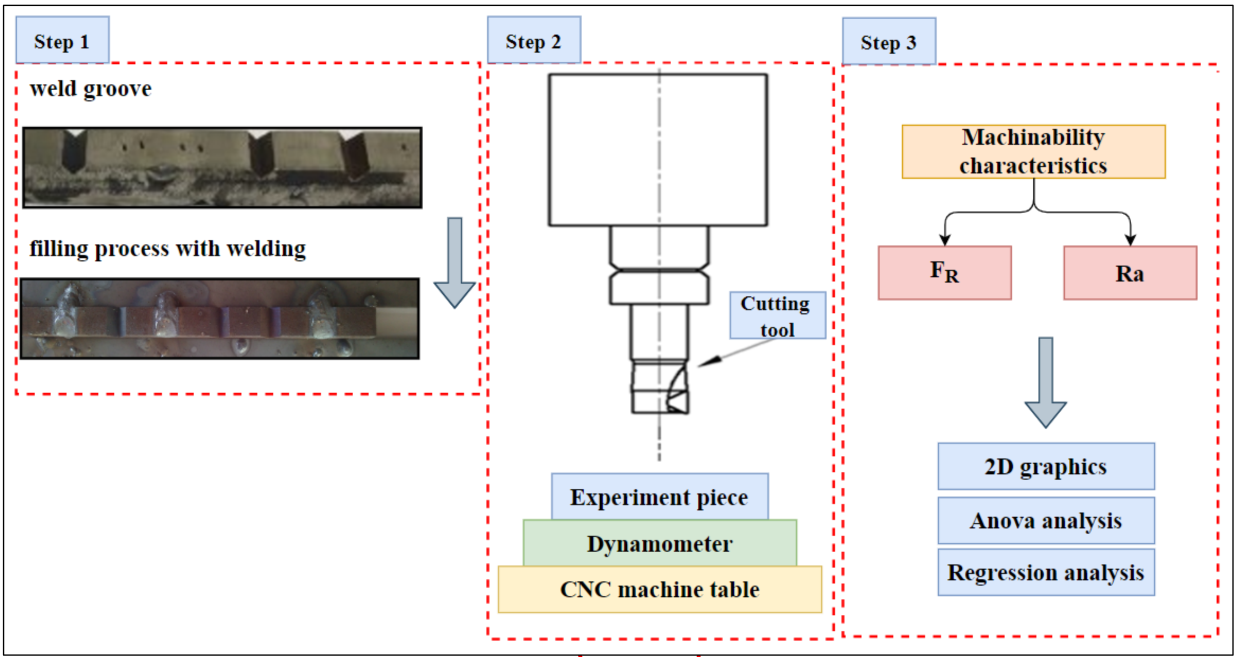

Figure 1. Stages of the experimental study (Deneysel çalışmanın aşamaları)

Table 1. Technical specifications of Buğra MIG 650 SW welding machine (Buğra MIG 650 SW kaynak makinasının teknik özellikleri)

Mains voltage (V)	3x380	**Dimensions (mm)**	460x1360x980
Idle operating voltage (V)	22-49	**Maximum on-board power (KVA)**	27
Welding current adjustment range (V)	50-650	**Wire diameter that can be used (mm)**	1.0-1.2.1.6-2.0-2.4
Wire feed speed range (m/min)	1-24	**Weight (kg)**	247

Table 2. Technical specifications and mechanical properties of SG2 welding wire (SG2 kaynak telinin teknik özellikleri ve mekanik özellikleri)

Chemical composition (%)			**Yield Strength (MPa)**	**Tensile Strength (MPa)**	**Impact Strength (J)**	**Elongation (%)**
C	Si	Mn	min. 420	500-640	min. 47	min. 22
0.08	0.85	1.45				

The cold work tool steel DIN 1.2379, which is extensively utilized in the industry, was chosen for the experimental investigation. Specimens measuring 20x20x100 mm were used as workpiece material. Table 3 provides the chemical makeup of the material utilized in the experiment. In order to make the welding process easier, 60˚ weld grooves were opened on the parts.

Table 3. DIN 1.2379 Chemical composition of the material (DIN 1.2379 Malzemenin kimyasal bileşimi)

Material	Hardness (HB)	Chemical composition (%)							
		C	Mn	P	S	Si	Cr	Mo	V
DIN 1.2379	229	1.59	0.25	0.023	0.0006	0.33	11.34	0.72	0.74

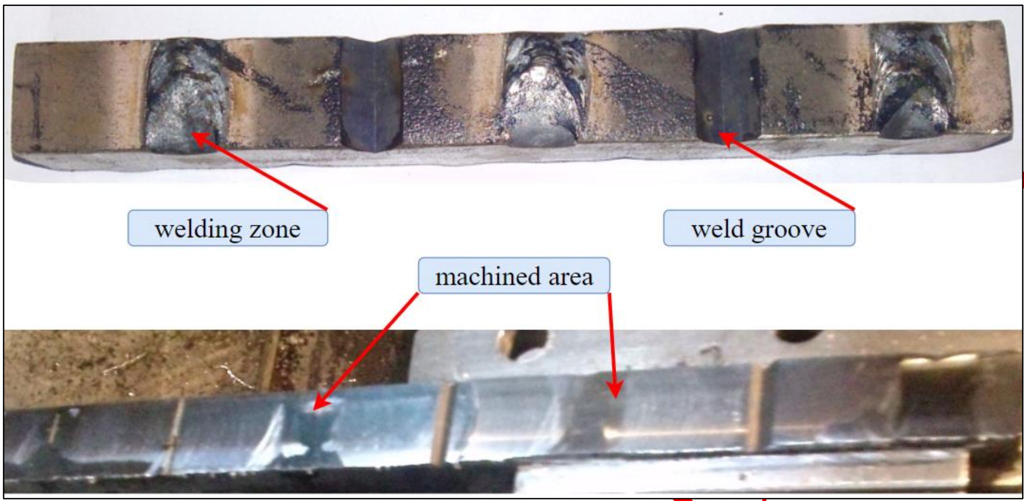

Figure 2. Welded and machined parts (Kaynaklı ve işlenmiş parçalar)

The trials employed PVD-coated TiAlN-coated cemented carbide inserts (GC1010-490R-08T308M-PM) made by Sandvik Coromant. CoroMill 490-032A25-08L coded tool holder with cylindrical shank, 32 mm diameter machining capacity, and 90˚ edge milling angle was used as tool holder. On a CNC milling machine, machinability tests were conducted using the parameters specified in ISO 8688-1. Before the experiments, the welded area was cleaned and the slagged part was processed. The values of the cutting parameters were determined with reference to the manufacturer's data. The experiments were carried out under dry conditions at three different cutting speeds (80, 100, 128 m/min), three different feed rates (0.10, 0.15, 0.20 mm/rev), and 0.3 mm cutting depth. The machining experiments were carried out on a Johnford VMC550 BSD vertical machining center with a power of 5.5 kW using a Fanuc control unit located in the Industrial CNC laboratory of Gazi University Faculty of Technology, Department of Manufacturing Engineering. With a Kistler 9257B three-component piezoelectric dynamometer, cutting force measurements were carried out. This dynamometer is connected to a Kistler 5070A multichannel charge amplifier. The cutting force data were then analyzed using Dynoware software. The symmetrical face milling method was used for milling the welded areas. This method allows the calculation of the resultant force (F_R). The components of the cutting force acting on an insert of the cutting tool in face milling are expressed in Figure 3.

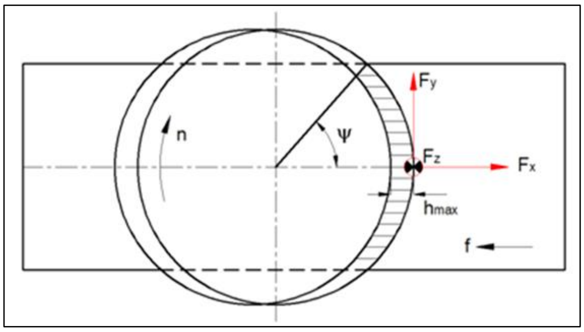

Figure 3. Cutting geometry in symmetric face milling (Simetrik yüzey frezelemede kesme geometrisi)

In this way, F_x is the instantaneous feed component, F_y is the instantaneous normal component, and F_z is the instantaneous vertical component. The immediate resultant force on the workpiece is known as F_R. A is the cutter's instantaneous cutting angle, while F_x, F_y, and F_z are the immediate cutting forces on an insert with feed in the X, Y, and Z directions, respectively. Equation 1 was used to compute the resultant force [15-17].

$$F_R = \sqrt{\left((F_x)^2 + (F_y)^2 + (F_z)^2\right)} \tag{1}$$

Measurement of roughness was done using the profile approach. For this purpose, a portable MAHR-Perthometer M1, which can read the profile change in terms of Ra, Rz, and Rmax, was used. After the samples were machined to 100 mm length, the measurement process was carried out without waiting in order not to oxidize the surfaces and affect the measurement values. The average surface roughness (Ra) values investigated in the study were obtained according to ISO 4287 standard [18]. Ra values were also determined by averaging the results of three measurements taken from each machined surface. The sample length (λ) was 0.8 mm and the measurement length (L) was 4 mm.

3. Experimental Results and Discussion (Deneysel Sonuçlar ve Tartışma)

The resultant force (F_R) and surface roughness (Ra) values resulting from milling experiments using the cutting parameters were measured, and the numerical values are given in Table 4. Figures 4 and 5 show the variations in F_R and Ra values based on feed rate and cutting speed.

Table 4. Cutting parameters and experimental results (Kesme parametreleri ve deneysel sonuçlar)

Exp. no	Feed rate (mm/rev)	Cutting speed (m/min)	F_R (N)	Ra (µm)
1	0.1	80	399	0.146
2	0.1	100	559	0.126
3	0.1	128	564	0.100
4	0.15	80	518	0.181
5	0.15	100	685	0.162
6	0.15	128	757	0.146
7	0.2	80	653	0.226
8	0.2	100	675	0.190
9	0.2	128	857	0.174

3.1. Evaluation of F_R (F_R'nin değerlendirilmesi)

The change in F_R values in relation to feed rate and cutting speed is depicted in Figure 4. Examining Figure 4, it is evident that F_R values rise as cutting speed increases across the board for all feed rates.

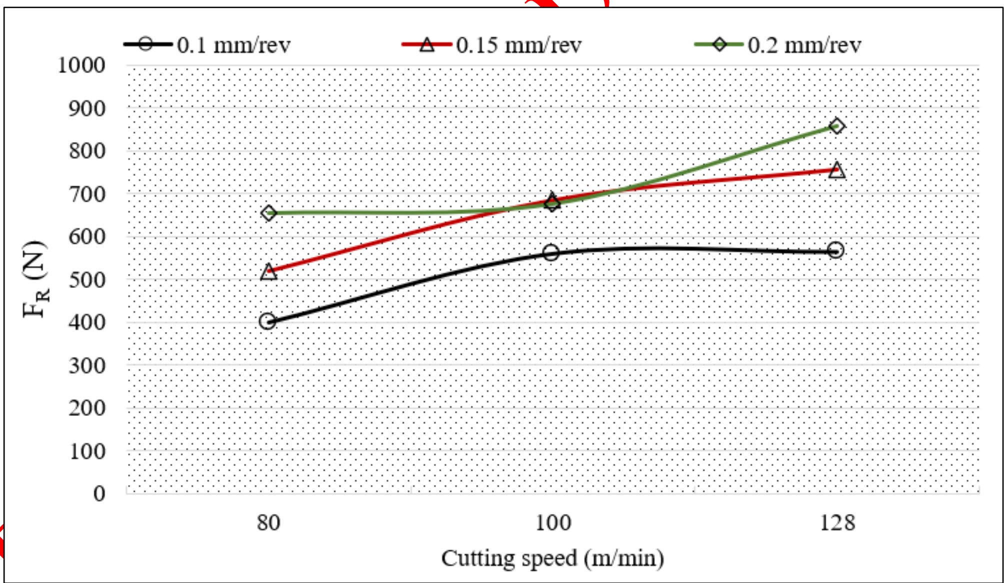

Figure 4. Variation of F_R depending on cutting parameters (Kesme parametrelerine bağlı olarak F_R'nin değişimi)

With the increase in cutting speed, F_R values increased between 5% and 65% at all feed rates. This can be explained by the high Si content in SG2 wire, which increases the yield strength of the material and wears the cutting tools rapidly at high cutting speeds. At all cutting speed values, F_R values rose as feed rate increased. This increase can be attributed to the increase in both the amount of material removal and the resistance encountered during cutting with increasing feed rate [19].

3.2. Evaluation of Ra (Ra'nın değerlendirilmesi)

The variation of Ra values with regard to feed rate and cutting speed is depicted in Figure 5. Analyzing Figure 5, it is evident that Ra values fall at all feed rates as cutting speed increases. This may be explained by the fact that when cutting speed increases, temperature rises as well, which causes the adhering material's strength in the second deformation zone to diminish. The material with reduced strength is deformed more easily, and the chip flows more easily away from the cutting zone

[20-22]. As with the F_R values, Ra values rose as the feed rate increased at all cutting speed values. As the feed rate increases, the distance between the marks that each insert leaves on the workpiece during the metal removal process (feed marks) increases. Greater feed rates cause these markings to become more noticeable, which causes the surface to ripple deeper and more pronouncedly [23]. This is thought to be effective on surface roughness.

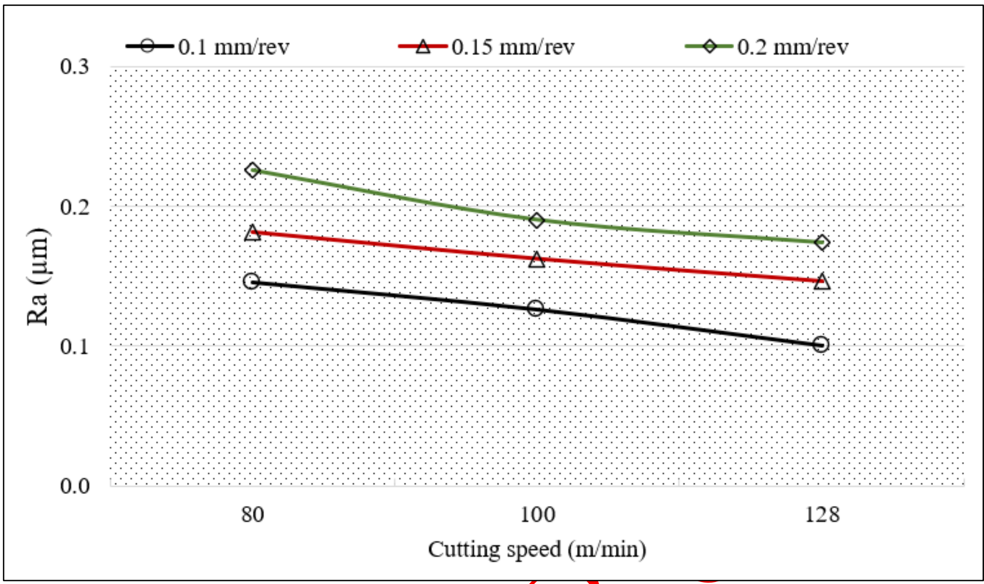

Figure 4. Variation of Ra depending on cutting parameters (Kesme parametrelerine bağlı olarak Ra'nın değişimi)

Anova results of F_R and Ra values are presented in Table 5. The biggest value of F is the factor that has the greatest influence on F_R and Ra among the values that were found by computing the sum of squares of each component independently. Table 5 illustrates that the feed rate was the primary factor influencing both F_R and Ra. The effect rate of feed rate on F_R is 51.02%, while on Ra it is 72%.

Table 5. Anova results (Anova sonuçları)

Parameter	**DF**	**SS**	**MS**	**F**	**P**	**PRC (%)**
F_R						
Feed rate (f)	2	75782	37891	14.17	0.015	51.02
Cutting speed (Vc)	2	62061	31030	11.61	0.022	41.78
Error	4	10695	2674			7.20
Total	8	148538				100
R-sq= 92.80%, R-Sq (adj)= 85.60%						
Ra						
Feed rate (f)	2	0.007913	0.003956	121.66	0.000	72.00
Cutting speed (Vc)	2	0.002948	0.001474	45.32	0.002	26.82
Error	4	0.000130	0.000033			1.18
Total	8	0.010990				100
R-sq= 98.82%, R-Sq (adj)= 97.63%						

Regression analysis is used to describe the relationship between a dependent variable and one or more independent variables. The F_R and Ra values obtained for this experimental study are given in equations 2 and 3 as first order equations.

$$F_R = 52 + 1013f + 2.40Vc + 11.7f^{*}Vc \tag{2}$$

$$Ra = 0.1301 + 0.830f - 0.000755Vc - 0.00101f^{*}Vc \tag{3}$$

Regression equations were obtained by considering the feed rate (f) and cutting speed (Vc) factors. R^2 is the coefficient expressing the appropriateness of the regression equation. As the R^2 value approaches 1, it is accepted that the statistical closeness of the regression model expressing the relationship between the dependent and independent variables increases.

In this context, R^2 values for F_R and Ra are 0.9028 and 0.98, respectively (Figure 6-7). In this case, it is concluded that the regression model makes a good prediction and the study is in line with the realities.

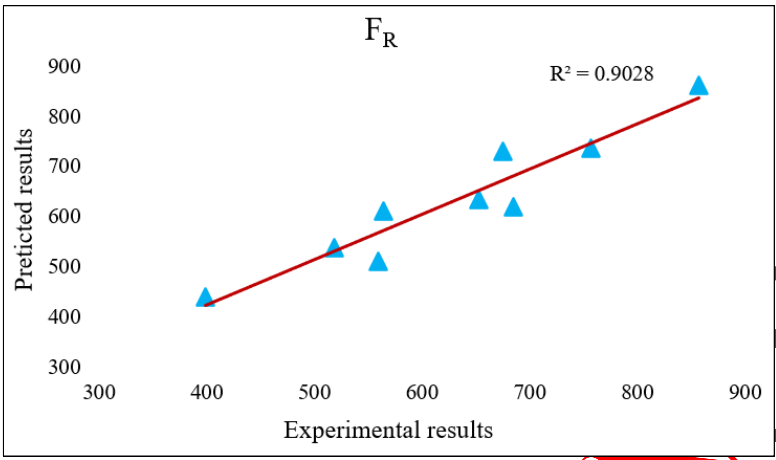

Figure 6. Comparison of F_R results (F_R sonuçlarının karşılaştırılması)

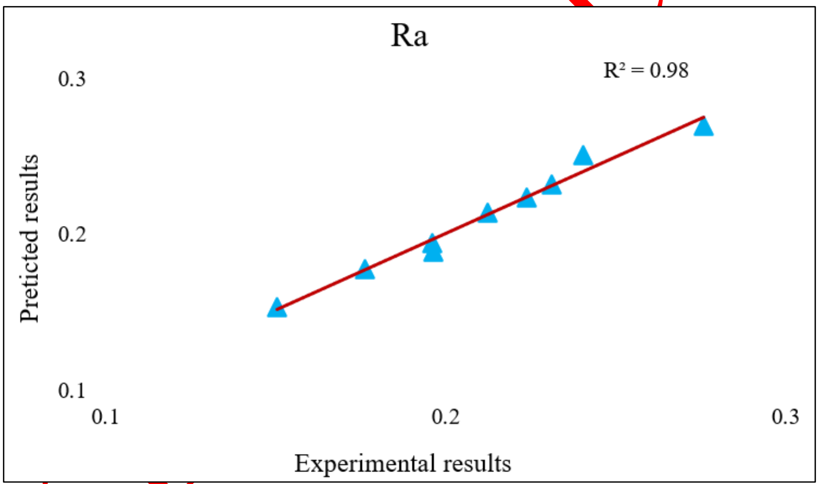

Figure 7. Comparison of Ra results (Ra sonuçlarının karşılaştırılması)

4. CONCLUSIONS (SONUÇLAR)

The results obtained as a result of the machinability tests of the filler welding process on DIN 1.2379 material are summarized below.

- At constant feed rates, it was shown that F_R values rose as cutting speed increased. This is attributed to the high Si content in SG2 wire, which increases the yield strength of the material and wears the cutting tools rapidly at high cutting speeds.

- At constant feed rates, it was found that Ra values dropped as cutting speed increased.

- An Anova study revealed that the feed rate was the primary factor influencing both F_R and Ra. The effect rate of feed rate on F_R is 51.02%, while on Ra it is 72%.

- The R^2 values obtained for F_R and Ra showed that the mathematical models developed to predict the machining outputs can be used with high reliability for milling the filler weld applied to DIN 1.2379 material.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Yusuf SİYAMBAŞ: He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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