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The investigation of cutting parameters for improving cutting performance in band saw machines

Şerit testere tezgâhlarında kesme performansını iyileştirmek için kesme parametrelerinin incelenmesi

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Abstract

Machine tools are required to be able to produce workpieces according to the desired technical requirements. The goal of machining is to achieve a high production volume of good quality with maximum tool life, short production time, and low cost. The surface properties obtained as a result of the changing and developing technology in cutting processes, the introduction to manufacturing, and especially the post-processing processes are of great importance. While the time obtained as a result of fast cuts has economic value, high-quality surface obtaining provides cost savings by minimizing the subsequent machining operations. Within the scope of the study, Ø120 mm ST-52 and Ø120 mm AISI 4140 materials have been cut with smart and automatic cutting modes by our domestic band saw machine. As a result of the cuts, the roughness values and curvatures of the samples have been checked with the surface roughness device and surface gauge. While the surface roughness after cutting was 4.45 µm with the automatic cutting mode, this value decreased by 16% to 3.71 µm with the smart cutting mode.

Keywords: Smart cutting, Surface roughness, Band saw machine, Cutting performance

Öz

İş parçalarını istenilen teknik gereksinimlere göre üretebilmek için takım tezgahlarına ihtiyaç vardır. Talaşlı imalatta amaç, maksimum takım ömrü, kısa üretim süresi ve düşük maliyet ile kaliteli ve yüksek üretim hacmi elde etmektir. Kesme işlemlerinde değişen ve gelişen teknoloji sayesinde, imalata geçiş ve özellikle son işlemler sonucunda elde edilen yüzey özellikleri büyük önem taşımaktadır. Hızlı kesimler sonucunda elde edilen süre ekonomik değere sahipken, kaliteli yüzey elde edilmesi bir sonraki talaşlı imalat operasyonlarını minimuma indirerek maliyet tasarrufu sağlamaktadır. Çalışma kapsamında yerli üretimimiz olan şerit testere makinası ile Ø120 mm ST-52 ve Ø120 mm AISI 4140 malzemeler akıllı ve otomatik kesim modları ile kesilmiştir. Kesimler sonucunda numunelerin pürüzlülük değerleri ve eğrilikleri yüzey pürüzlülük cihazı ve yüzey mastarı ile kontrol edilmiştir. Otomatik kesme modu ile kesim sonrası yüzey pürüzlülüğü 4.45 µm iken, akıllı kesme modu ile bu değer %16 azalarak 3.71 µm olarak tespit edilmiştir.

Anahtar kelimeler: Akıllı kesim, Yüzey pürüzlülüğü, Şerit testere makinası, Kesme performansı

1 Introduction

The band saw machines work on the rotation and feeding of the band sheet with the help of wheelers. To provide maximum cutting performance and tool life, tooth pitch and tooth geometry are among the most important parameters in band saws [1]. Today, machines using machining methods such as band saws are pioneers in the development of the global economy, especially in the automotive and aviation industry [2]. The goal of machining is to achieve a high production volume of good quality with maximum tool life, short production time, and low cost [3]. Studies involving sawing were first carried out on circular and band saws in the 1950s. In the 1960s, a cost comparison of cutting with the band saws and arm saws, and research on the cutting economy were made. The changes in specific cutting forces and the effects of cutting parameters such as cutting speed and feed on cutting forces were investigated in cutting various materials, taking into account the saw geometry in cutting in band saw. Ünüvar et al., in their study, determined that an increase in feed rate causes an increase in cutting forces [4]. Band saw is often preferred indifferent industries for cutting raw materials into customer orders due to its low notch loss, high metal removal rates, and competitive surface quality characteristics, it is frequently preferred in various industries for cutting raw materials into customer-ordered pieces. They observed that it led to a better understanding of cutting with a band saw by examining the effects [5]. The amount of sawdust removed by each tooth is not proportional to the load in sawing. Depth of cut cannot be selected for each tooth in saw cutting. Progress control; is carried out by the thrust load between the workpiece and the cutting insert. Tooth design, cutting speed, feed rate, and chip formation mechanism are the factors affecting cutting performance. The rotational movement of the band saw is achieved by driving the wheels by the electric motor. In the articulated

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band saw table, the part of the table called the head is articulated from one end to the main body. The head descends with a rotational movement around the joint, the cutting process takes place Ünüvar et al. investigated the effect of cutting parameters on tool wear in band saw and formed the tool life equation. Material hardness, feed rate, and cutting speed, respectively, have the greatest effect on wear; They observed that the particle sizes had the least effect [6]. Due to the lack of continuous cutting capability, it has been understood that the cutting process with a band saw has higher distortions and a smooth cutting surface compared to cutting with laser cutting, plasma cutting, and circular saw [7]. Yilmaz et al. The tool performance in the cutting process of AISI 1020 material with the flat saw, which has a wide usage area in the manufacturing industry, was investigated. A computer-controlled cutting machine was used in the experiments, and the feed and cutting speed was chosen as fixed parameters for the determination of the cutting performance of the saw. A total of 80 experiments were carried out and boron oil was used as the cooling liquid. Microcracks formed by the cutting process were visualized by scanning electron microscopy (SEM). With the start of the cutting process, the cutting forces increased rapidly and remained stable after a certain time. The largest forces are the F_x forces in the shear direction. With the increase of the F_x force, the tooth fracture dimensions are minimal [8]. Cheng et al. have studied some innovative design concepts and especially force-based smart cutting tools, temperature-based internal cooling cutting tools, and smart cutting tools [9]. Meng et al. With the finite element numerical simulation of Ansys/ls-dyna, the changes in stress, and shear force during the cutting of mulberry branches with a circular saw were analyzed. It provides a theoretical basis for optimizing circular saw blade parameters, and extending service life [10].

Sönmez and Sögütlü studied the surface roughness and cutting parameters of acacia, pear, chestnut, sessile oak, and Cedrus libani woods cut in tangential and radial directions on a 250 mm diameter, 24- and 48-tooth circular saw. Rough-textured wood materials gave rougher surfaces than fine-textured ones. The roughness is higher in the radial direction. As a result of their studies, they suggested that the rough-textured wood materials should be cut by increasing the number of incisors [11]. In Ni, the transverse vibration of the band saw blade in the sawing operation is a well-known cause of band saw wear, material loss, and poor surface quality of the workpiece. Five types of surface textures with an inverted triangle structure on the band saw blade was developed for the saw to study their effects on transverse vibration. Developed surface texture on the band-saw blade to reduce transverse vibration for sawing [12]. Quintana and Ciurana review the research situation regarding the vibration problem and classifies existing methods developed to achieve stable cutting as those that are out-of-process or in-process, those that change the system passively or actively [13]. R. Okai et al., in their study, cut wood with a band saw with a random pitch. They present their experimental results showing the surface profile of the workpiece when cut with stellite-tipped saws and jigsaws under both laboratory and industrial conditions [14]. Kremlava et al. showed that the eigenfrequencies of bending-torsion vibrations of band saw blades and the limits of active regions can be displayed as a function of tool parameters and operating conditions.. The width of the regions of instability depends on the excitation coefficient and is mainly determined by processing. By means of the analytical formulas obtained, the dynamic instability regions can be determined as a function of the relevant parameters [15]. Taylor and Thompson have obtained the band saw's wear rate and cutting speed the relationships between related parameters such as the machine load and the geometry of the workpiece. Wear rate and shear rate were expressed in terms of a shear constant that describes the penetration of teeth and their decay with use. They used a computer-based simulation of the band sawing process to investigate the effects of relevant engineering parameters on productivity and the cutting economy. It shows that when the thrust load, feed rate, and band saw cutting speed increase, the cutting speed reaches its maximum, the cutting cost decreases to a minimum, and the blade life decreases [16]. AISI 4140 tempered steel, which is one of the test materials, contains a high amount of carbon due to its alloy and therefore it is in a structure suitable for hardening. The ratio of Mn and Cr in its main component provides high strength and toughness. ST-52 refers to general structural carbon steel containing up to 2% carbon.

This material is suitable for use in welded steel constructions subject to variable and constant stresses. With this study, which was carried out in an industrial environment, the effects of artificial intelligence-machine learning on the process result in the machine manufacturing sector were examined and the improvement was numerically proven. In this study, Ø120-sized ST-52 and AISI 4140 materials were cut in smart and automatic cutting mode. ST-52 and AISI 4140 materials were cut in two different cutting modes, smart, and automatic cutting modes. As a result of the experimental studies, the cut curvature and surface roughness of the test samples were measured. The improvement in smart and automatic cutting modes is examined by taking the cutting times as a reference.

2 Materials and methods

In the study, the importance and advantages of production with adaptive control in the saw machine, which is less in number than the machine tools in the literature, are emphasized. The effect of variable cross-section and variable parameters on the cutting surface quality and cutting time was investigated during cutting in the sawing machine. This study, it is aimed to examine the cutting improvements of two different cutting modes in two different materials with the same diameter (Ø120mm), by taking the cutting time and cutting surface quality as a reference. The test materials used in the study were preferred because of the frequency of use in the industry and their different hardness scales. The chemical compositions of the materials used in the study are given in Table 1 and Table 2.

The Brinell hardness of the materials preferred to be cut within the scope of the study is given in Table 3.

Table 1. ST-52 Chemical composition (wt %)

C	Si	Mn	P	S	F
0.22	0.55	1.60	0.030	0.03	Balance

Table 2. AISI 4140 Chemical composition (wt %)

Cr	Mn	C	Si	Mo	S	P	Fe
0.8-1.10	0.75-1	0.380-0.430	0.15-0.30	0.15-0.25	0.040	0.035	Balance

Table 3. The hardness of the cut materials

Material	Hardness (Brinell HB)
ST-52	165
AISI 4140	197

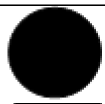
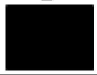
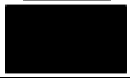
The experiments were carried out in Kar Metal company, which produces band saw and circular saw machines, with the ULTRA 300x300 Full automatic band saw machine shown in Figure 1. Smart cutting technology stands out as one of the most important features of the machine. 13,000 materials classified according to 6 different standards have been saved in the machine's library. In addition, it has capabilities such as automatic selection of cutting parameters that are most suitable for cutting channels, material quality, heat treatment, sawing mode, blade type, and blade TPI according to predefined parameters in the database.

Figure 1. ULTRA 300x300 Fully automatic domestic band saw machine (Production of Kar Metal Company in Turkey)

In addition, in Table 4, the maximum cutting capacity of the ULTRA 300x300 Full automatic band saw machine is given with the geometry information. In this study, tests were carried out with a diameter Ø120 material cut in a circular geometry. In the study, a WIKUS/Marathon M42 model 54x1.6 bimetal hook tooth 2/3 tpi band saw was used. This saw has a hardness of 68-69 HRC.

In the cutting process performed with a WIKUS/ Marathon brand bimetal bladed band saw which is made of bimetal materials such as alloy steels, high-speed steels and carbon steels, blade length is 7220mm, blade width is 54 mm, blade thickness is 1.6 mm, 2/3 saw tooth type and boron oil as cooling fluid were used Figure 2.

Table 4. Ultra 300x300 band saw machine cutting capacity

Material Geometry	Cut Angle (0°)
	300 mm
	300 mm
	300x330 mm

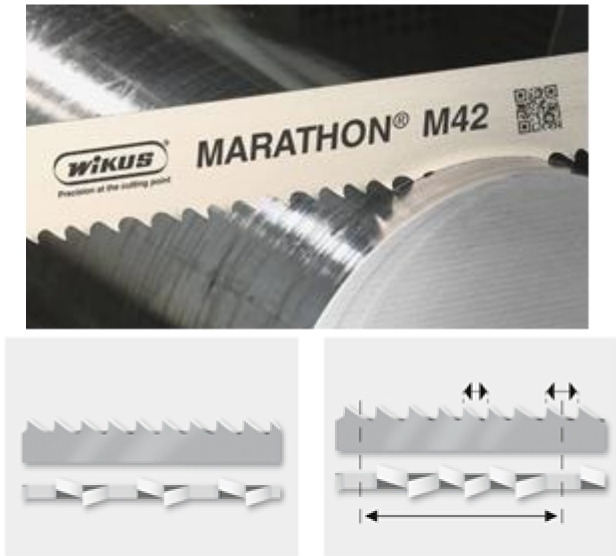
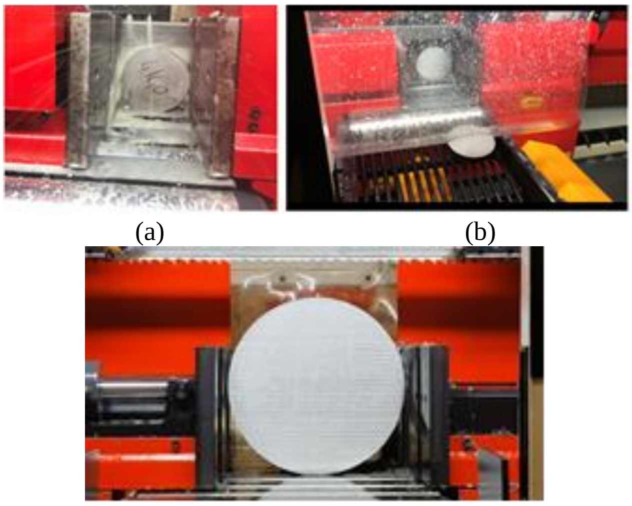


Figure 2. Marathon bi-metal band saw blade hook tooth 2/3 tpi

The cutting process can be followed instantly on the Karmetal Ultra 300x300 machine, which can perform high-performance fast cutting, the cutting operation of which is shown in Figure 3. The cutting speed can reach a maximum of 400m/min in the latest model band saw machine with the main engine power of 21kW. This band saw machine, which works with the latest technology, calculates the most suitable cutting parameters and cuts depending on the type and dimensions of the material to be cut.

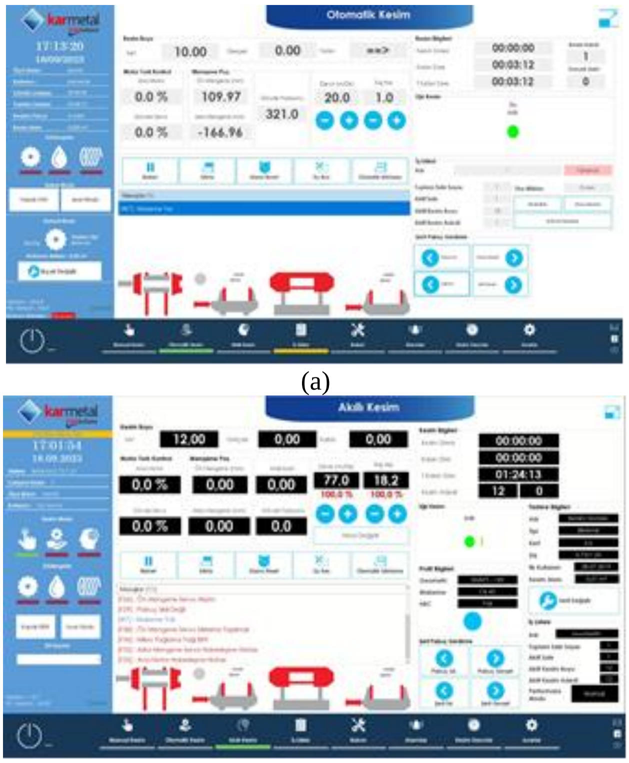
For the smart mode, materials included were defined to the band saw machine, classified according to material properties, and the most appropriate parameters were taught to the machine with calculations. The material to be cut is prepared for the cutting process depending on parameters such as material geometry and heat treatment. In smart cutting mode, since the cross-sectional tracking of the part is performed, the strip speed and descent speed are updated in real-time thanks to the machine parameter software.

As a natural output of this information, it has been observed from the interface that the cutting process slows down when the diameter of the piece is reached during the cutting process. In the study, the most suitable cutting parameters were determined on the materials to be cut and these parameters were taught to the machine. Parameters; Cutting speed, Feed rate, Cooling lubricant, blade booth pitch. With the database prepared by the knife manufacturer, the most appropriate parameters were added to the experimental setup. Thus, without the need for an operator, the most suitable parameters for the relevant material are called from the library and the cutting process is carried out. One of the important features of the smart cutting process is that the cutting parameters are recalculated depending on the strain during cutting. In addition, critical data during cutting is stored on a cloud server to be interpreted in artificial intelligence.



(a) (b) (c)

Figure 3. Cutting process (a) cutting moment (b) after cutting (c) before cutting



(a) (b)

Figure 4. Operatorpanel interface (a) Smart cutting mode operator panel, (b) Automatic cutting mode operator panel

In the smart cutting mode (Figure 4a), the value seen when the active cross-section measures 120 is the value kept constant for the automatic cutting mode (Figure 4b). Figure 4a and Figure 4b show the digital display when in smart and automatic cutting modes. In smart cutting mode, cutting speeds change instantly. During cutting, the measurement in the part cross-section changes the saw rotation speed and the body stroke speed. When the section size decreases during cutting, the cutting speed increases as the amount of sawdust that the blade can remove will increase.

Since the instant cross-section of the part is monitored in smart cutting mode, the strip speed and descent speed are updated in real-time thanks to the machine parameter software. For example, when cutting a solid cylinder material, it cuts faster at the point where it starts but cuts slower when it reaches the middle of the material. The feed rate increases and decreases instantaneously depending on the material cross-section change. In the automatic cutting process, the widest length of the material to be cut is taken into account and the cutting and feed speeds are determined based on this section length.

In this study, the Mitutoyo brand Surftest SJ-210 model surface roughness measuring device was used. In order to maintain the precision in the measurement, control measurements specified on the calibration plate of the device were made at the end of every 100 measurements. After the device was adjusted to 2.5 mm measuring steps and 3 cut-offs, the measuring arm was placed between two lines with 17 mm spacing.

3 Results and discussion

After the study, the cutting times of the materials, the cut surface roughness values, and the curvature results of the test samples were examined with two different cutting modes. As seen in Table 5, It has been observed that the cutting speed slows down when the largest section of the piece is reached in the smart cutting mode and the speed increases as the section contraction, which has a positive effect on the cutting time in cutting the piece. In smart cutting mode, variable cutting speed and descent speed occur depending on the section change. This situation decreases the cutting time when it increases the speed when it comes to the narrow section during cutting. As the cross-section grows, the amount of sawdust removed from the part increases. This reduces the cutting speed and landing speed. As a result, the cutting time increases. According to the literature, the current study was conducted not to directly affect the calculation of blade life, but to see the improvement in cutting quality and improvements were observed [4,16].

Table 5. Cutting time results

Cutting Material	Mode/ Cutting Time(s)	
	Automatic	Smart
ST-52	189	184
AISI4140	170	173

While the active cross-section is at its lowest level, the feed rate is at its maximum. In this study, this value is 48.92 mm/min. With this result, it is seen that it directly affects the cutting time. In automatic cutting mode, the cutting time is extended. When cutting ST-52 material with automatic mode, the time is longer by 7% compared to the smart cutting mode, and by 10% for AISI4140 material. Surface roughness values were taken from the samples in case the surface quality was compromised by saving time.

Surface roughness results are shown in Table 6. According to the results, it was observed that the surface quality increased with the reduction of the cutting time in the sample cutting made with the smart cutting mode. The fact that the measured surface roughness values are low indicates that the surface quality has increased. In the study, the vibration output during cutting can be reached in the results obtained with the surface roughness device. The determination of the region of instability was achieved by the surface roughness results taken from the cut sample. (Kremlava et al, 2016) One of the most widely used parameters is the mean of the average height difference for the average surface. It provides for stable results as the parameter is not significantly influenced by scratches, contamination, and measurement noise (Eq(1)).

$$R_a = \frac{1}{l}\int_0^l Z(x)dx \qquad (1)$$

Table 6. Average surface roughness results

Material	Cutting Mode/Surface Roughness (Ra(µm))	
	Automatic	Smart
ST-52	4.519	4.45
AISI4140	4.11	3.71

In Table 7, the table in which the data is followed instantly during cutting, which is one of the machine features, is given. With data flow and instant monitoring, you can monitor the instantaneous section, cutting speed, feed speed, etc. A software system has been developed to monitor the features.

In Figure 5, the main motor and servo motor stresses for all cuts can be examined. As can be seen in the figure, the amount of current drawn from the servo motor for both materials in automatic cutting mode increases when it reaches a quarter of the cutting. The percentage of power drawn from the servo motor is measured by the software integrated into the machine. This shows that the current drawn from the servo motor is the same in any section of the part in smart cutting mode, but the percentage of current is variable in automatic cutting mode.

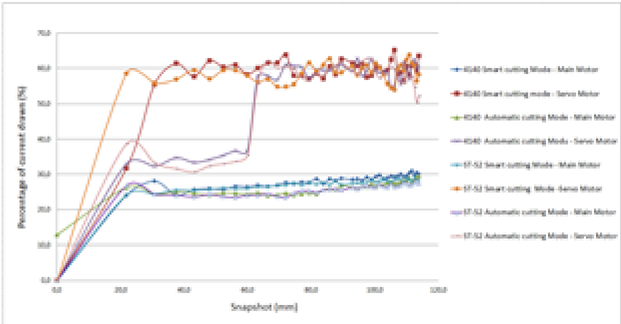


Figure 5. Main motor and servo motor stresses for all cuts

In the cut samples, the inclination of the piece was checked as perpendicular to the cutting direction and the cutting direction. With the help of the measuring device, the height (elevation) was measured differently, from the part cutting entrance part to the exit. In order to calibrate the measuring instrument before the measurements, Johnson measuring instrument was used, this process was carried out at room temperature, the reliability of the device was tested and measurements were taken from the samples after calibration Figure 6 (a), (b).

(a) (b)

Figure 6. (a) Surface roughness device, (b) Sample skew check

The cutting direction of ST-52 and AISI 4140 materials and their inclination at the entrance and exit perpendicular to the cutting direction in smart and automatic cutting modes related to sample curvature are given in Figure 7.

Table 7. Data extraction

Sowblade Motor	Machine Body Motor		Saw blade Speed	Landing Speed	Cutting Type	Material Type	Active cross-section (mm)
Main Motor Power (%)	Absolut evalue (Servo Power) (%)	Servo Power(%)	(Speed m/min)	Landing Speed (mm/min)			
24.12	58.5	-58.5	71	48.92	Smart	St 52-3	21.8
24.23	60.7	-60.7	71	48.92	Smart	St 52-3	21.8
23.63	56.1	-56.1	71	48.92	Smart	St 52-3	21.8
24.26	61	-61	71	48.92	Smart	St 52-3	21.8
24.40	55.8	-55.8	70	48.23	Smart	St 52-3	43.1

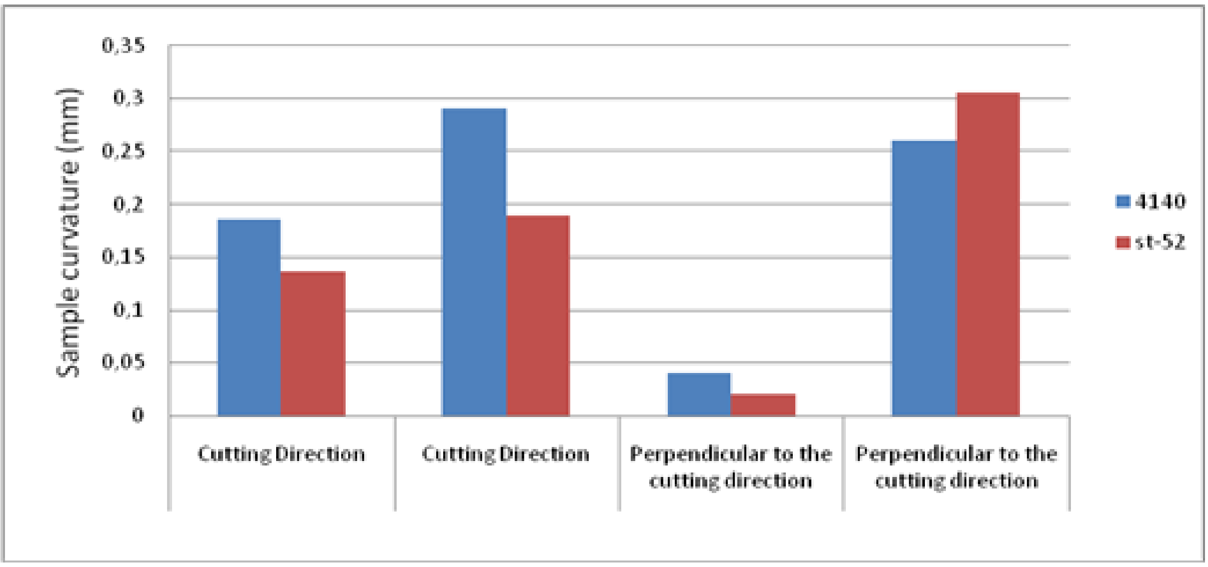


Figure 7. Sample curvature results

It is seen that this difference is much lower in the samples measured perpendicular to the cutting direction in the smart cutting mode compared to the other samples. It is known that the most influential parameters during cutting are cutting speed and landing speed, cutting tip (blade) material, and types [10]. Adaptive smart machining makes machining processes smart to a certain extent. It presents the concept and innovative use of adaptive smart machining through an adaptive control system with constraints, based on feed rate adjustment for orthogonal cutting force by a smart cutting tool developed in their work [17].

In his study, Sun presented an internally cooled cutting tool for dry cutting, along with other applications for adaptive machining purposes, as a temperature-sensing smart cutting tool in its own right. The cutting tool is characterized by a simple exchangeable internal cooling structure near the insert [18].

The adaptive control system is a system that provides machine optimization by detecting changes in the tool system. A good adaptive control system monitors the working status of the machine tool, while at the same time transmitting the changes in the system to the user and providing the system optimization itself. Sample curvature results are given in Table 8. It is seen that the highest value is the measurement taken from the cutting direction in the automatic cutting mode and the lowest value is the measurement taken perpendicular to the cutting direction in the smart cutting mode. These results proved that the sample curvature after cutting is lower in smart cutting mode. Smart cutting mode is provided by adaptive control. The machine works adaptively as there is a cross-section change during the cutting of cylindrical materials. Thanks to the variable section, an improvement in cutting time can be observed with variable cutting parameters.

According to Table 8, the cutting surface results obtained from the cuts made with the automatic cutting mode are rougher than the smart cutting mode. Since St 52 material is a softer material than 4140, it is an understandable result that the surface quality of St 52 is worse than 4140. An inference can be made due to material hardness (Table 3).

Table 8. Sample curvature results

Material	Cutting Mode	The direction of measurement	Skew difference
ST-52	Smart	Cut direction	0.136
ST-52	Automatic	Cut direction	0.19
AISI 4140	Smart	Cut direction	0.186
AISI 4140	Automatic	Cut direction	0.29
ST-52	Smart	Perpendicular to the cutting direction	0.02
ST-52	Automatic	Perpendicular to the cutting direction	0.306
AISI 4140	Smart	Perpendicular to the cutting direction	0.04
AISI 4140	Automatic	Perpendicular to the cutting direction	0.26

4 Conclusions

Two different types of material (St-52 and AISI 4140) in Ø120 mm size have been cut with two different cutting modes (smart and automatic). As a result of the cuts, the roughness values of the samples were checked with the surface roughness device, and the curvature of the samples was cut with the help of a gauge. According to this;

- When the cuts made in two different modes are examined, it is seen that the cutting time is shorter in the smart cutting mode, as the cutting parameters change depending on the cross-section.
- When the surface roughness data is examined, the surface quality in cutting AISI 4140 material decreased by 16% in smart cutting mode compared to automatic cutting mode. In ST-52 material cutting, this rate is 9%. The curvature of the piece taken with the help of the gauge was examined and it was seen that the smart cutting mode cuts less curvature and better quality samples in both materials.
- It has been observed that the amount of current drawn from the servo motor during cutting is variable in automatic cutting mode. We can conclude that the reason for

this is that the smart cutting mode carries out active cross-section tracking so that the current is drawn.

- Compared to the literature, the increase in tool life and machine usage time has been associated with the use of cutting modes embedded in the machine. High surface quality and long working life are possible with the smart cutting mode that works with instantly variable parameters. It makes it easier to produce high-precision parts close to perfection, enabling more efficient production using adaptivity control. Damage of cutting inserts used in machine tools. Provides longer bench life by preventing.

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Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 16%

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