Investigation of Increasing the Tooth Surface Quality of Curvilinear Involute Gears

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INVESTIGATION OF INCREASING THE TOOTH SURFACE QUALITY OF CURVILINEAR INVOLUTE GEARS

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ABSTRACT

It is not possible to increase the surface quality of non-standard gears with curved involute tooth profile produced by 5-axis CNC milling method with standard gear grinding methods due to curved tooth profiles. In this study, the possibilities of increasing the surface quality of non-standard gears with curved involute tooth profile were investigated in order to expand their use in the industry. For this purpose, the target model was produced by using the mathematical parametric equations of the involute curve that forms the profile form of a tooth in the CAD environment. By using the target model, manufacturing codes were derived in the CAM environment, and gears with curved involute tooth profile were produced on a 5-axis CNC machine. Then these gears; The possibilities of increasing the tooth profile surface quality were investigated by applying four different methods, such as precision finishing, co-running in oil, co-running in oil with SiC added, and grinding on a 5-axis CNC machine with a finger grinding tip specially produced for gears. In the oil co-run method, considering the running-in stage for each method, the gears were tested with the help of the designed gearbox, at a revolution speed of 670 rpm, by turning a total of 150,000 turns in 6 periods of 25,000 turns. In the co-start method, the gears at the beginning of the test and at the end of each period; thermal records, noise analysis, photographic records, surface roughness values (Ra, Rz) were measured. In the co-operation methods applied to increase the surface quality, the tooth surface of the gears at the beginning of the test and at the end of each period; photographic records, surface roughness values (Ra, Rz) were measured, noise levels were measured during the test and thermal records were taken. Similarly, in precision machining and grinding methods, photographic recordings of the tooth surface were taken, surface roughness (Ra, Rz) was measured, micrographs were taken in SEM and analyzed after the process. As a result of the tests and analyzes carried out; It has been observed that the surface quality is the best in the process performed using a specially produced finger grinding tip and a CNC grinding machine.

Key words: Non-standard gears, tooth profile grinding, 3d modeling, CNC

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1. INTRODUCTION

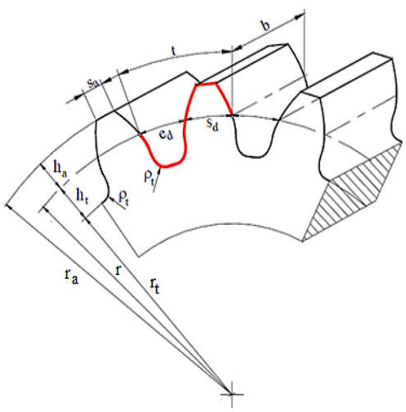
Gears with curvilinear tooth profile, which were first introduced in the first quarter of the 20th century, compared to standard gears; It has been reported that less bending and contact stresses, better balance of axial loads, more load bearing, quieter operation and better lubrication properties [1, 2]. In order to take advantage of its prominent features and to expand its use in the industry, a special manufacturing machine was developed, some special tools and tool holders were manufactured to be used in traditional vertical machining centers, and curvilinear gears were manufactured [3-10]. However, the nominal shape of the curved involute tooth profile could not be fully reflected in the produced gears, and form deviations occurred in the tooth profile [11-13]. In recent years, besides the production of standard gears, target models of these gears have been created in the CAD environment, and different physical conditions have been simulated on the target model in the digital environment and analyzed. As a result of these analyzes, it has been revealed that with the optimization of the curved form created along the tooth on the target model, both the curve form of the gears and the nominal shape of the tooth profile can be accurately manufactured using a 5-axis CNC machine [14-18]. It has been reported that the surface quality of tooth profiles should be increased in order for these gears to be widely used in the industry. It has been noted that well-finished machine components exhibit lower friction, operating temperature and wear [19]. Good surface finish means higher productivity for gear systems [20]. For the surface finishing process, the surface finishing process by sandblasting, grinding or polishing is chosen considering the representative roughness [21]. Surface conditions are often different in the running-in stage compared to steady-state conditions due to wear and/or transfer. For this reason, care must be taken when finishing the gears with the lapping method. Gear grinding is a method used for accurate gear finishing on CNC machines via computer subsystems for finishing or roughing gears [22]. The method supports serial gear production with precise tolerances of surface quality and geometric form. In the literature study, the lack of such a study was noticed and the possibilities of gear surface quality enhancement were investigated by using different methods to increase the surface quality of gears with curvilinear involute tooth profile. For this reason, an experimental study was carried out by using gear pairs with curved involute tooth profile to improve the surface quality, by testing the effects of different finishing methods on the product quality of gears. The results of roughness measurements, thermal analysis, noise analysis and microstructure analysis, as well as other influence factors, were tried to be revealed to analyze the product quality with the motivation to determine the interactions and relationships between the gears and the interactions and relationships between the applied surface finishing processes.

2. MATERIAL AND METHOD

Gears from machine elements are one of the basic components of almost all machines and modern systems. Gears must meet certain desired requirements, including lifespan, power transmission, efficiency and quiet operation. The efficient operation of gear systems can be achieved by developing and coordinating components with each other in terms of function-related features such as size, shape, position accuracy as well as surface quality, as well as the seamless cooperation of components. A good finish is an unavoidable requirement to eliminate material distortions to meet productivity and surface quality requirements. In this study, the methods of increasing the surface quality of tooth profiles of gears with curved involute tooth profile were investigated.

2.1. Gear Generation Process

In this study, the methods of increasing the surface quality of tooth profiles of gears with curved involute tooth profile were investigated. For this purpose, gear basic sizes were determined by using equations (1)-(10) in order to produce gears with curved involute tooth profile (Fig. 1).



Şekil 1. Gear basic sizes [3].

$$h_a = m \tag{1}$$

$$S_a = 0{,}166.m \tag{2}$$

$$t = \pi.m \tag{3}$$

$$S_d = t/2 \tag{4}$$

$$e_d = t/2 \tag{5}$$

$$h_t = 1.166.m \quad (6)$$

$$h = 2{,}166.m \quad (7)$$

$$d_t = m.z \quad (8)$$

$$D_a = dt + 2.m \quad (9)$$

$$D_t = dt - 2{,}166.m \quad (10)$$

Here; d_t pitch circle diameter (mm), b tooth width (mm), D_a over tooth diameter (mm), D_t base circle diameter (mm), h tooth height (mm), h_a over tooth height (mm), h_t root height (mm), S_a is the tooth thickness (mm), S_d is the tooth thickness (mm), ρ_t is the radius of the bottom arc (mm), t is the scale, e_d is the tooth gap (mm). After determining the basic sizes of the gears, in order to create the parametric geometric model of the gear profile (Fig. 2), the involute curve was created in the SOLIDWORKS program by using the parametric equations (11)-(12) of the involute curve (Figure 3. a). The target model of the gears was created by using the gear sizes obtained from these curves (Fig. 3.b). The target model of the gears was created by using the gear basic sizes obtained with these curves (Fig. 3.b).

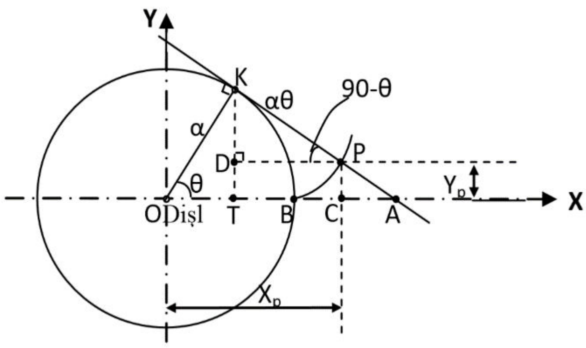


Fig. 2. Evolvent curve formation geometry [3].

$$X_p = a.(cos\theta + \theta sin\theta) \quad (11)$$

$$Y_p = a.(sin\theta - \theta cos\theta) \quad (12)$$

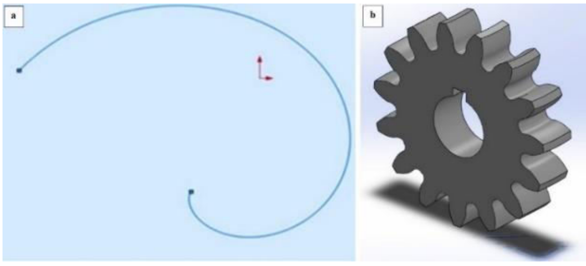


Fig. 3. A) Evolvent curve, b) Curved gear target model created in CAD environment

After the target model of the gear with curved involute tooth profile was created, machining simulations were made using the SOLIDCAM program, CAM manufacturing codes were derived and the gears were manufactured using a 5-axis CNC machine (Fig. 4).

Fig. 4. Gear pair produced on CNC machine.

Phenomena such as feed rate, tool deflection and tooth geometry or chip formation and vibration of the tool-workpiece system and the kinematic effects of relative motion between them have adverse effects on the tooth surface quality of milled gears. In addition to these disadvantages, the impact nature of milling, the rotation speed of the cutting tool due to the spindle and the conversion of a large part of the energy consumed during the cutting process into heat also reduce the surface quality of the gear teeth. For these reasons and because their modified geometries do not allow an alternative manufacturing method, it is necessary to increase the surface quality of these gears, which are manufactured by milling method, in order to increase the technological quality and product life span of the product. An important indicator of the technological quality of the product is the surface roughness. A good surface quality, which has a large-scale effect on the production cost, can be achieved with a finishing process. In order to increase the tooth surface quality of the gears, a total of 8 equal-sized gears were manufactured to be used in the finishing processes.

2.2. Experimental set-up

As the first method to increase the tooth surface quality of gears, precision machining method was preferred (in the finishing stage) in order to see the possibilities of precision machining with CNC in increasing the surface quality. This method, which was applied by trial and error method, refers to the knowledge standard of the processing machine and the operator, but recently, in parallel with the improvements in CAM software, the process has moved to an important point in the design of processing parameters with statistical methods (Tauguchi method). Here, as the gear pair machining parameter whose surface quality is investigated with this method, spindle speed " 2500 rpm ", feed rate " 300 mm / min ", feed in the vertical direction 1mm, depth of cut " 0.5 mm ", pass feed "0.5mm" , thickness of the finishing pass " 0.5 mm ", tool lateral slip value " 60% " in roughing, spindle speed " 4500 rpm " in finishing, feed rate " 300 mm/ min ", vertical feed 0.05mm, chipping depth is set as " 0.05 mm ".

As the second method, the gearing method was used. In this method; The normally milled gear pair was run without any strain in commercially available Petrol Office Maxigear EP-X 85W-140 transmission oil, the typical properties of which are given in Table 1.

Tablo 1. Typical properties of Petrol Office Maxigear EP-X 85W-140 oil

Sae Viscosity Grade	SAE J 306	85W-140
Density,15˚C, COC	ASTM D-4052	0,908
Flash Point, ˚C, COC	ASTM D-92	226
Kinematic Viscosity 40˚C, cSt	ASTM D-455	395.6
Kinematic Viscosity 100˚C, cSt	ASTM D-445	27.53
Viscosity Index	ASTM D-2270	105
Pour Point, ˚C	ASTM D-97	-15
Foam Test, ml	ASTM D-892	5
II. Level		0
Brookfield Viscosity -26˚C, İn cP	ASTM D-2272	80000
Copper Strip Corrosion 100˚C, 3st	ASTM D-130	1b
	ASTM D-5185	
Elemental Analysis mg/kg	P	490
	S	22390

In the third method; Lapping, which is very effective and widely used in the mating of hypoid gears, has been taken as a reference due to the geometric closeness in the tooth profiles of gears with curved involute tooth profile. In the third method; Lapping, which is very effective and widely used in the mating of hypoid gears, has been taken as a reference due to the geometric closeness in the tooth profiles of gears with curved involute tooth profile. In the industry, this process is used to remove the cutting tool traces left over from the gear machining and to correct the errors in the gear geometry [23]. In the lapping process, the gear pair was run in opposing oil without any strain. SiC commonly used in practice; It is chemically inert, insoluble and extremely hard (Mohs hardness 9.4), has high thermal conductivity, low coefficient of thermal expansion, thermal shock, abrasion and high temperature resistance. In the run-in method in oil containing abrasive, SiC powders with particle size ≤ F240 FEPA Grit (Federation of European Producers of Abrasives) (F240 = 44 μm) were mixed as abrasive particles in the carrier oil at a rate of 20% by weight. During the oil run-in, a gearbox was designed and manufactured in a CAD environment to complete the running-in phase of the gear pairs and reveal the responsive behavior and surface roughness change under steady-state conditions (Fig. 5).

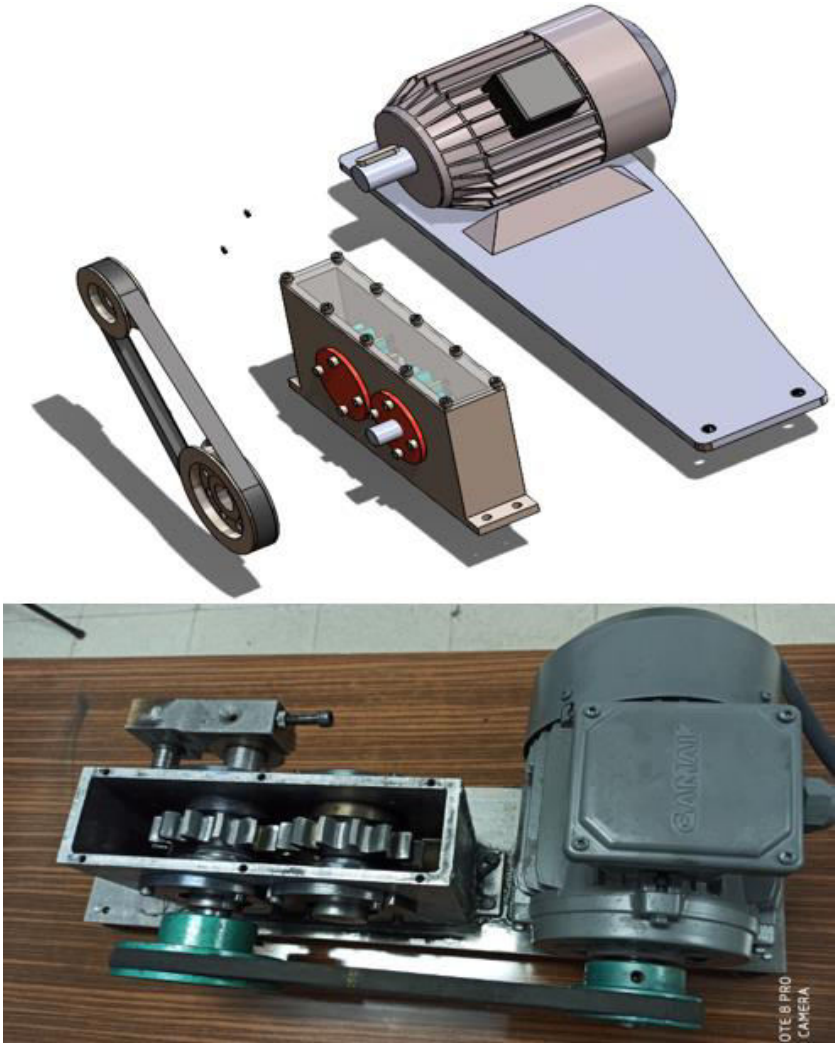


Fig. 5. CAD model and real photo of the manufactured gearbox.

Tests were carried out by running the produced gears in oil and oil containing abrasives by being driven by a belt-pulley system and electric motor (670 rpm) without being subjected to any strain. The number of rotations of the gears of 25,000 turns was taken as a constant parameter for each period and they were tested with a total of 150,000 rotations (6 periods). At the end of each period, the gears were disassembled and washed with solvent (gasoline), the gear surfaces were cleared of oil and wear residue particles, and surface roughness measurements were carried out (Fig. 6).

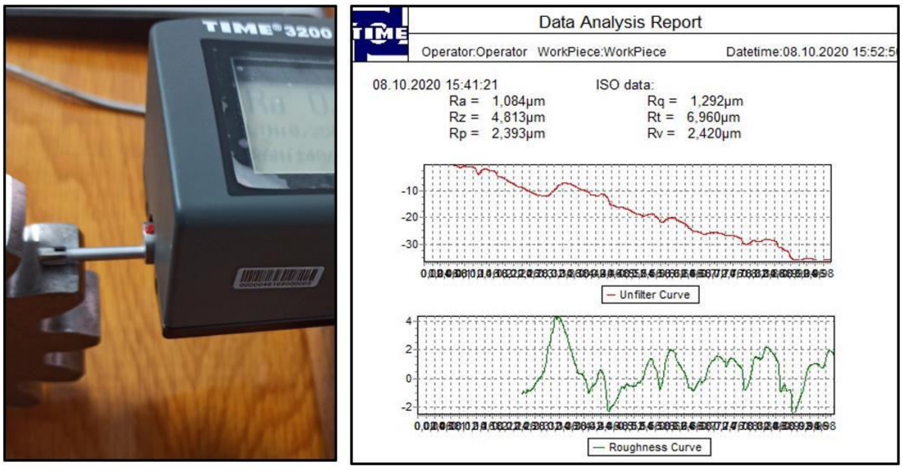


Fig. 6. Surface roughness measurements in surface roughness tester.

Surface roughness measurements of the gears used in the tests; In the TIME3200 tracer-tipped surface roughness tester; Cuttoff: 0.25 mm, Acces: 3, Range: +/- 80 μm, Filter: Gauss, Standard: ISO 4288, Unit: Metric System measurement conditions (Fig. 6). As surface roughness parameter in the surface roughness measurements of gears; Ra and Rz values, which are used to measure surfaces of compression or contact lapping, are also taken into account. For each gear pair, tooth surface roughness measurements of a gear were made. Based on eight randomly determined teeth of each gear, roughness measurements were made for both the right and left wings and for the middle, and the arithmetic average value of the total 24 surface roughness results was calculated and reflected in the graphics. After the surface roughness measurements, a photograph of a randomly selected tooth was recorded.

2.3. Gear Sound Noise Analysis

Because gear mesh responses are very sensitive to tooth surface geometry and topographic index, modifications to tooth flank geometry and topographic index, depending on the treatments applied, cause the gear system to significantly alter its vibration and noise characteristics. In order to report this variation and analyze the response of gear pairs as a function of process type and number of periods, Sound noise level measurements were made in each period during the tests. Hercolor Mini USB Sound Noise Level meter for measurements (LCD-Display: 4 Digits 0.5 Secretary Measurement-Level: 0 ~ 120 db (A) (A-weighted decibel), 20 – 100db (C) (C-Weighted decibel) accuracy: 1.5 dB Frequency response: 31.5 HZ ~ 8.5 KHZ resolution: 0.1 dB dynamic range: 50 dB/100 dB

Ueberlastanzeige:/Under frequency evaluation) measurement test device is used. For both methods, the maximum sound noise level measured during each period was recorded and graphed as a function of the number of rounds determined for the periods.

2.4. Thermal Analysis

Experimental investigations on the thermal behavior of gears, due to the increased tooth flank surface resulting from the modified geometry of curvilinear gears compared to their peers' standard gears, have noted that high temperatures are induced [24]. The characteristic reflections of the transmission kinematics and the changing contact pattern and lapping methods due to the modified geometry in the tooth contact region of the gear pair produced by milling, as it increases the temperature and noise level of the working gears, it causes the oil film layer between the contact surfaces of the gears to rupture. In contact areas where there is no oil film layer, metal-metal tribo pairs are formed and short-term local boiling and then ruptures occur between the surface temperatures increasing due to friction with each other and the topographic index of the tooth side surfaces. As a result of these adhesions and ruptures, significant modifications occur in the microstructure and texture of the gear side surface. During the tests, thermal records of the tests were taken with the Testo 871 thermal camera at every period in order to detect and report the thermal response of the gears according to the process type, to determine whether the oil used is within the viscosity index depending on the temperature formed, and to analyze the thermal reflections of the transformation in the surface quality of the gears at the end of the periods. (Fig. 7).

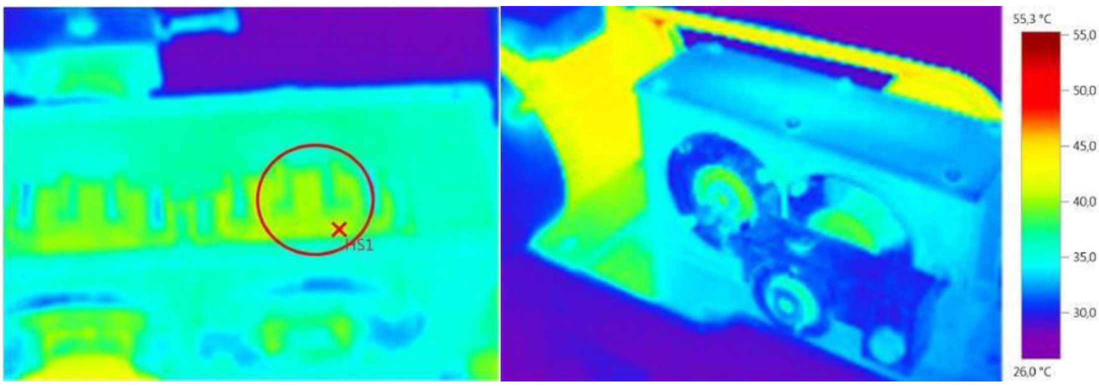


Fig. 7. Break-in tests Gearbox thermal imager recording.

2.5. Gear Grinding

Grinding provides a high-quality surface that can also be applied to heat-treated gears, correcting tooth surface deterioration, increasing the dimensional accuracy of the tooth profile. Grinding is the most preferred method in mass production because it allows gear finishing with short cycle times, high precision and high surface quality [25]. With this motivation, grinding was chosen as the fourth and last method among the methods used to increase the tooth surface quality of the gears. Curved involute gears cannot be grinded with the methods applied to standard gears due to their modified geometry. For this method, the process relies on the interactive motion between the grinding wheel and the workpiece, which entails the necessity of producing the grinding wheel to directly fit the geometry of the gear tooth. One of the biggest obstacles in the finishing process of gears with curved involute tooth profile is how to flexibly finish the curved tooth side topographic surface of the gear. Since the grinding method with a CNC milling machine and a grinding tip designed according to the tooth profile has sufficient degrees of freedom to produce convex and concave shaped topographic modification of the tooth surfaces, the grinding obstacle has been removed and has come to the fore more than other methods [26]. Since the tooth profiles of the gears have a convex-concave form, a new grinding method has been tried in the grinding of these gears. For this reason, the curve used in the tooth formation of gears (Fig. 3. a) was also used in the modeling of the grinding tip with an involute profile by using the SOLIDWORKS program (Fig. 8).

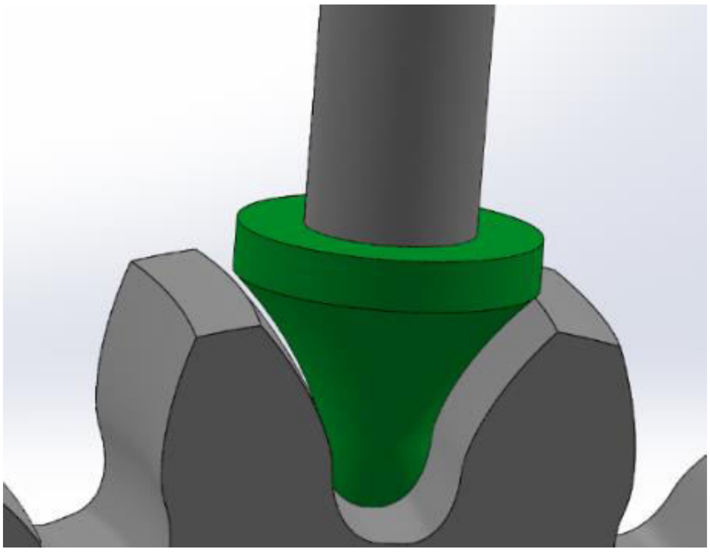


Fig. 8. Cylindrical grinding point CAD model.

Thanks to the 5-axis CNC machine and this design, the grinding obstacle caused by the geometry (caused by the convex and concavity) of the gear, which has a curved involute tooth profile whose geometry has been changed, will be eliminated. The grinding tip, which is modeled by considering the gear geometry, will enter between two opposing tooth forms and move along the curvilinear tooth profile, and it will be possible to grind the gear easily with this method. Due to the removal of material from the workpiece in grinding, the interaction between the workpiece and the abrasive grain, the sand must have certain material properties to meet the functional requirements. These features are; In order to maintain the sharp edge form and to ensure the continuity of chip production, the toughness and hardness value attributed to the bonds formed by the binder in the stone against breaking should be high [27, 28]. The sand particles used in the manufacture of the stone must have the necessary thermal stability and good thermal conductivity at high temperatures occurring during the process. It should have the necessary chemical resistance against chemical reaction with the coolant used during the process and the workpiece [29]. Natural or synthetic sand materials are mostly used as grinding stone material. Depending on the extent to which it has the characteristics required in the area where it will be used, natural or synthetic sand material is preferred [28]. Grinding tip designed for grinding gears as sand material; Corundum (α-aluminum oxide) was preferred because of its advantages such as being able to be used for grinding hardened and unhardened steel, and being economical and widely used [27, 29]. Using the SOLIDCAM program, the curvilinear motion of the grinding tip was simulated and the CAM codes of the machining were derived. These codes were transferred to the 5-axis CNC machine and the curved gears were grinded. In addition to the main rotation of the grinding tip, additional oscillating movement in different axes has been achieved thanks to the possibilities of the CNC machine. The grinding spindle is located in the conical bush and the machine is driven by the spindle.

2.6. Micro structure Analysis

In order to determine the plastic deformations and thermal effects on the tooth surfaces of the gears and the modifications caused by different process dynamics, by applying the finishing methods determined as the research subject in this study, a random tooth was taken from each of the gears for microstructure analysis after the finishing processes and etched with HCl acid after solvent washing. Micrographs were taken with a ZEISS EVO 40 Scanning Electron Microscope (SEM) equipped with EDX (Energy Dispersive X-ray).

3. RESULT AND DISCUSSION

The nominal shape of the modified geometries of gears with curved involute tooth profile can only be accurately reflected on the real part with a 5-axis CNC machine with minimum form deviation and dimensional error, but this production process produces a rough tooth flank. This entails the necessity of proper finishing for these gears to ensure maximum efficiency and the gear working exactly as it should. In order to increase the surface quality of gears with curved involute tooth profile, precision finishing method was applied as the first method to the gears that were milled on a 5-axis CNC machine and the surface roughness of these gears was measured (Fig. 15) and the tooth surface photographed (Fig. 9. b).

Fig. 9. Milling on 5 axis CNC machine a) Normal, b) Precision fine, c) Grinding processed tooth profiles.

The surface roughness parameters after precision machining were measured as Ra=0.6694 μm and Rz=2.8668 μm. In order to increase the surface quality of the gears, two different lapping methods were applied, which mechanically abraded the gear surface. Gear pairs produced on a 5-axis CNC milling machine with normal machining parameters were applied with operating oil in these processes, while in the third method, with reference to lapping (particle size ≤ 44 μm = F240 grit FPA), SiC abrasive particles were applied. For both methods, photographs of the tooth surfaces were recorded for the gears before processing and at the end of each period (Fig. 10).

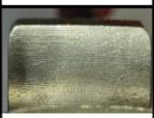
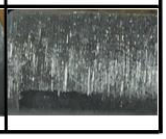
Number of Rounds	Milling Phase	25.000	50.000	75.000	100.000	125.000	150.000
Lubrication (Normal)							
Lubrication (SiC Added)							

Fig. 10. Transformation of tooth surface quality of gears with running-in methods according to periods.

Surface roughness was measured for both methods, and the arithmetic mean of Ra and Rz values was calculated and plotted (Fig. 11-12).

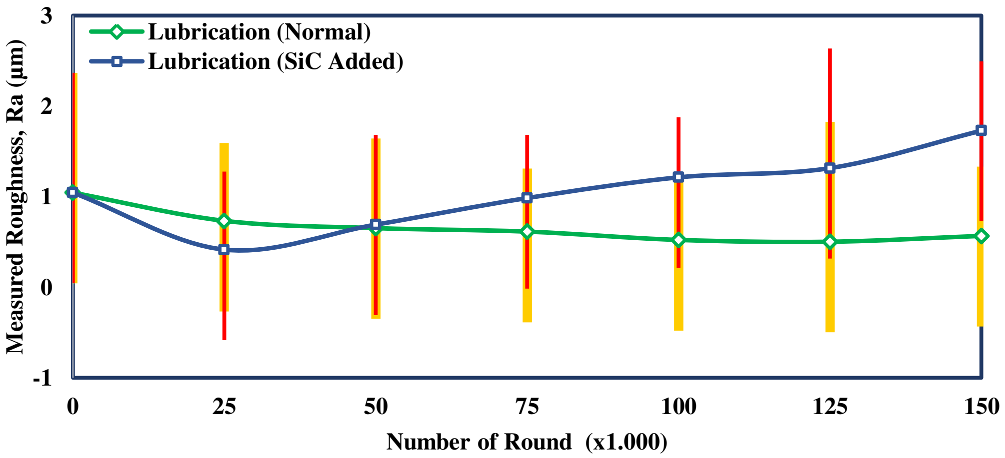


Fig. 11. Variation of tooth surface quality parameter Ra of gears with running-in methods according to periods

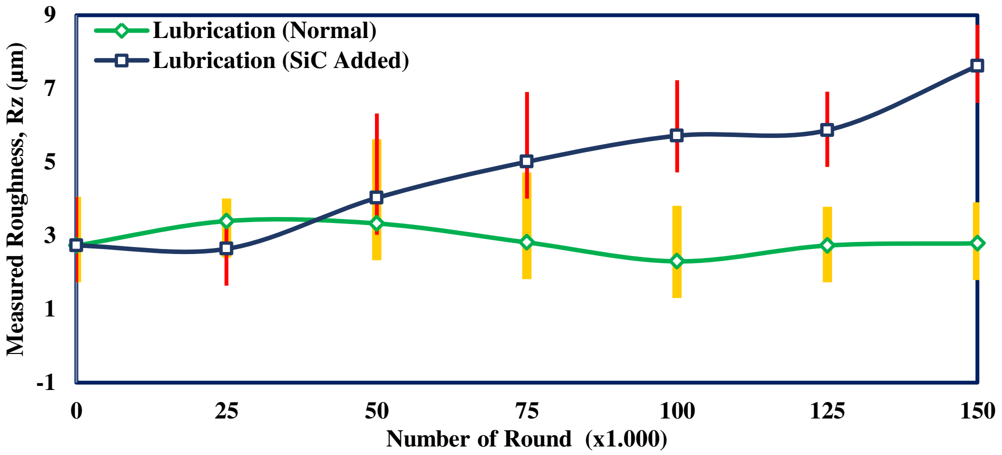


Fig. 12. Variation of tooth surface quality parameter Rz of gears with running-in methods according to periods

When the graphs of the surface roughness result (Fig. 11-12) are examined; The best surface quality was measured as Ra=0.5033 µm and Rz=2.2975 µm at the end of 125,000 rotations (5th period) in the running-in method in operating oil applied as the second method. In the third method where operating oil and abrasive SiC particles are applied together; the grinding material was abraded by the abrasive particles at the contact points, chipped from the tooth surface and approximately evenly (Figure 10). In this method, the best surface quality was measured as Ra=0.4162 µm and Rz=2.6375 µm at the end of the 1st period (25,000 rotations) in all periods. It has been observed that as the number of periods increases, a higher surface roughness results in wear beyond the nominal tooth profile and critical hardened layer thickness. When the graphs in Fig. 11 and 12 are examined, it is seen that there is a correlation between the roughness parameters Ra and Rz. The photographic recordings in Fig. 10 support this transformation in the parameters Ra and Rz, which is indicative of the surface quality in Fig. 11 and 12. The maximum noise level values determined in the noise level measurements in each period are plotted (Fig. 13).

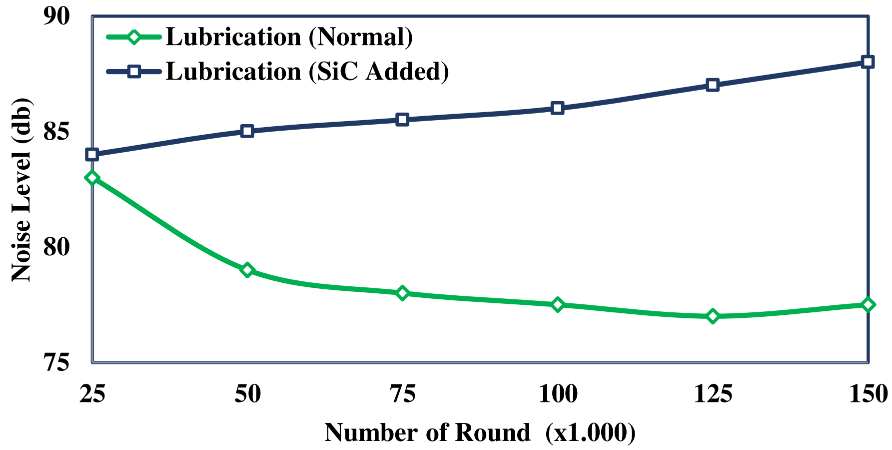


Fig. 13. Variation of sound noise levels of practice methods according to periods.

When the noise analysis graph of both methods and the graphs reflecting the surface roughness parameters (Ra and Rz) values are analyzed together, according to the process type and as a function of periods, a decrease in sound noise levels was recorded in parallel with the improvement in surface quality. For the second method (break-in in operating oil), the lowest noise level was measured at 77 dB in the 5th period of 125,000 rotations. For the third method (break-in with operating oil and abrasive SiC), the lowest noise level was measured as 84 dB during the 1th period of 25,000 rotations. In the tests of the second and third methods, the maximum temperature value determined from the thermal records of the gearbox in each period was plotted (Fig. 14).

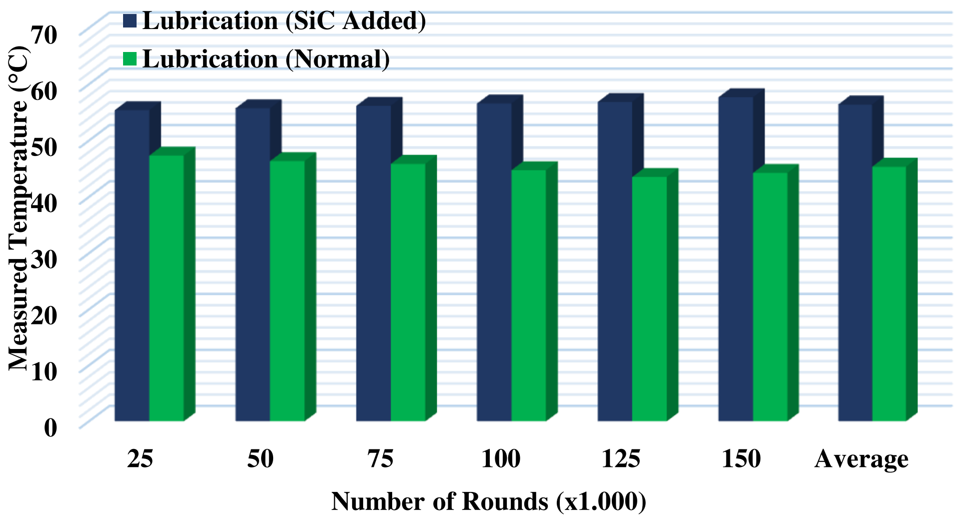


Fig. 14. The variation of the measured temperature value of the lapping methods according to the periods.

Due to the increased surface quality, a similar trend to decrease in noise analysis was observed in thermal recordings in both lapping methods. This trend differed in the number of periods during which the surface quality improved for both methods (Fig. 14). For the second method, the lowest temperature was measured as 43.54 ˚C in the period of 125,000 rotations, for the third method, the temperature was measured at 55.41 ˚C in the period of 25,000 rotations. The gear pair, which was grinded with the combination of a 5-axis CNC machine and a grinding tip designed and produced according to the tooth geometry, was finished by grinding in a shorter cycle time compared to other methods in the analysis of the test data, and the photograph of the tooth surface was recorded after the process (Fig. 9. c). By measuring the surface roughness for the grinding method, the arithmetic means of the Ra and Rz parameter values was calculated and plotted in order to be mixed with the results of all the finishing methods applied in this study (Fig. 15).

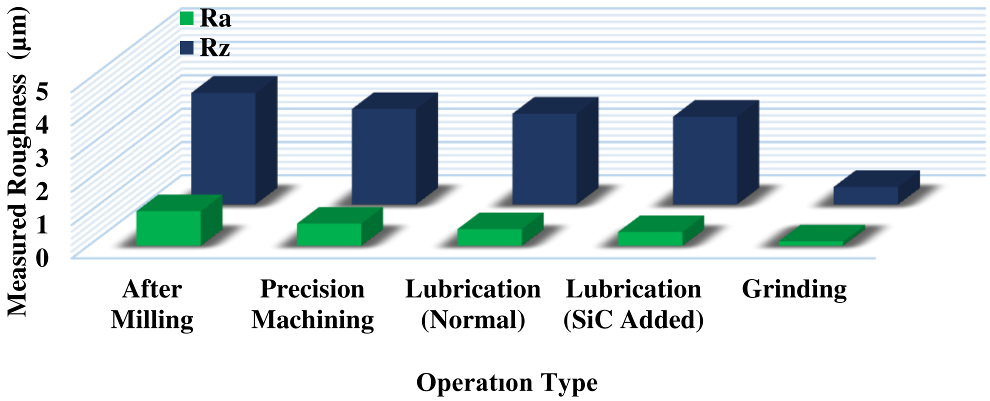


Fig. 15. The roughness values created by the applied surface quality enhancement methods

The surface roughness parameters after grinding were measured as Ra=0.1328 µm and Rz=0.5233 µm. The measured roughness values coincide with the photograph in Fig. 9.c. Grinding widely used in hardened standard gears is a method that can provide numerous cutting edges, high working speed and material removal rate, superior surface quality and very geometric form accuracy, and the results confirm this.

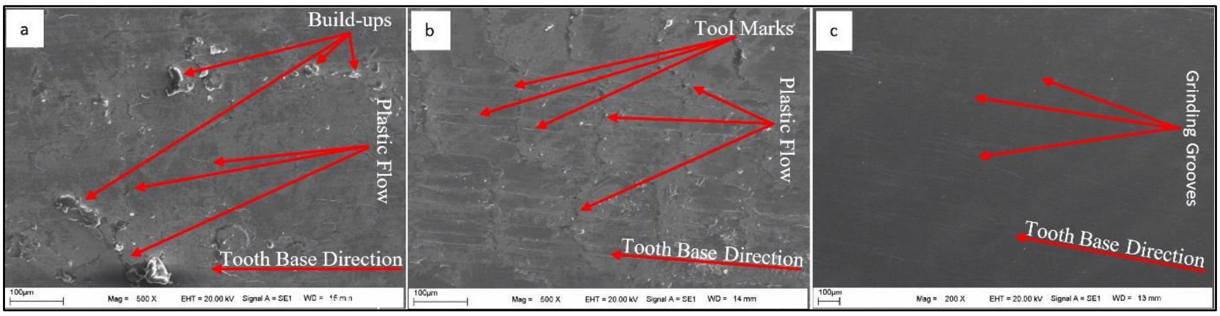


Fig. 16. Micrographs of tooth surface tissue taken in SEM of surface quality enhancement methods.

SEM micrographs of the gears (Fig. 16) support the roughness results graph of the methods applied to improve the surface quality (Fig. 16.). When the methods applied to increase the surface quality of curved gears are evaluated according to the results of the surface quality parameter values (Ra, Rz), it is seen that grinding gives better results compared to other methods. Surface quality with precision machining, which is the first of the regulations; it could be improved to a limited extent due to the technological and operator's knowledge standard of the machine used and the kinematic conditions of the relative motion (geometry) between the machine, tool and machined gear. SEM micrographs confirm this, but the processing time was too long and proved to be an unattractive method (Fig. 16.b). Using the run-in method applied in operating oil as the second method; it is safe for critical hardened surface thickness as the surface roughness is only improved by abrading the heights on the gear surface interact with each other. In gear contact, which is an open tribo system, wear residues are immediately removed from the sliding contact. In addition, with the lapping method; As scratches, scraping, plastic deformations and deep marks are gradually reduced, the tooth flank surface can be improved to a limited extent. The duration of each period is approximately 37 minutes and the best surface quality was achieved after a total of 185 minutes. It has been seen that this method cannot be an attractive method due to the limited improvement in surface quality and long cycle time. In the third method, run-in method with operating oil and SiC; Although it is an economical method of using less equipment (fine machining), tests have shown that the process must be controlled by an appropriate method in order to achieve the ideal surface quality. In deciding the ideal process time to reach the maximum surface quality; If a suitable indicator factor is not used, it has been observed that the limited hardened tooth flank surface formed by hardening will be thinned beyond the critical hard layer thickness by grinding, causing the gear to weaken against wear, mechanical stresses and damage, resulting in a reduction in product life. This method must be continuously monitored to maintain optimum form and maximum tooth surface quality, hardness and toughness, and the heat treatment hardened tooth flank surface only to remove imperfections and interference. It has been seen that the noise analysis data can be used as an argument in deciding the time required to reach the maximum surface quality. In this method, induction of higher temperature and noise with the presence of abrasive particles, decreasing viscosity of the operating oil on the contact surface with the effect of centrifugation; It made it difficult for the particles to adhere, causing a decrease in the number of abrasive particles on the contact surface and the process efficiency. Better results can be achieved if a higher viscosity operating oil and abrasive particles with a FEPA grit particle size are used. In the fourth method, which is similar to discontinuous grinding, the grinding tip produced; Between two opposing teeth, a lateral surface of both teeth and a grinding wheel surface contact, and the root fillet is ground together with the sides and the dangerous notch effect on the tooth root is prevented [30]. Due to the axial plunge movement of the grinding bit, the sand path, grinding grooves and surface profile topographic structure were formed parallel to the tooth base (Fig. 16.c). The grinding direction can be changed bidirectionally, in line with the tooth base and back and forth, so that gears can be produced comfortably and while grinding the gears, thanks to the discontinuity of the movement grinding contact, it provides less thermal effect and better cooling. The gap grinding process was carried out with the grinding tip profile, which is exactly the same as the finished tooth gap profile. Thanks to the 5-axis CNC machine and the involute profile form integrated into the grinding tip, higher surface quality can be achieved compared to other methods.

4. CONCLISION

In this study;

- Among the applied methods, grinding could be performed with better surface quality and less cycle time, and the surface quality of the gears was improved approximately 10 times.
- Due to their modified geometry, the grinding obstacle of curved gears, the degree of freedom that the grinding tip should have, is eliminated with the 5-axis CNC machine and the grinding tip produced in the tooth profile.
- The results of noise or vibration analyzes can be used to decide on the ideal treatment time and maintenance of the critical hardened surface thickness of the run-in method with abrasive SiC particles in the operating oil.
- In the lapping method with abrasive SiC particles in the operating oil; Better results can be achieved with a more viscous operating oil due to the induced high temperature and abrasive particles with a higher FPA grit particle size.

The results have been obtained. Providing maximum quality tooth surface with the lapping method used together with the operating oil and SiC abrasive particles; Experimental work can be done using noise analysis data to determine the ideal SiC abrasive particle size (FPA grit), optimum speed and processing time.

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Author contributions

MU: Supervision was in charge of all project management, formal analysis, arranging reviews and funding. ŞT: Supervision, review, official analysis, review arrangement. MSÇ: Research and conceptualization, original draft writing, review and editing. All authors have read and approved the final article.

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Competing Interests

The authors declare no competing financial interests.

Data Availability Statements

All data generated or analyzed during this study are included in this published article.

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