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Optimization of the Surface Roughness and Chip Compression Ratio of Duplex Stainless Steel in a Wet Turning Process Using the Taguchi Method

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Abstract: Duplex stainless steels (DSSs) are used in many applications due to their properties, such as high mechanical strength, good corrosion resistance, and relatively low cost. Nevertheless, DSS belongs to the materials group that is difficult to machine. The demand for a total increase in the production requires the optimization of cutting conditions. This paper examines the influence of cutting parameters, namely cutting velocity, feed, and the depth of cut on the surface roughness and chip compression ratio (CCR) after the DSS wet turning process. The study employed Taguchi optimization to determine the ideal cutting parameters for wet turning finishing operations on steel 1.4462. Using the Taguchi design, experiments focused on surface roughness (Ra) and CCR. Utilizing a TiAlN/TiN-PVD coating insert with a 0.4 mm nose radius, cutting velocity of 200 m/min, feed rates of 0.05 mm/rev, and cutting depths of 1 mm yielded the lowest R_a at 0.433 μm. Meanwhile, a cutting velocity of 200 m/min, feed rate of 0.15 mm/rev, and cutting depth of 0.5 mm resulted in the smallest CCR at 1.39, indicating minimal plastic deformation. The inclusion of additional cooling proved beneficial for surface roughness compared to dry and wet turning methods. The experimental data holds value for training and validating artificial intelligence models, preventing overfitting by ensuring sufficient data collection.

Keywords: turning; duplex stainless steel; surface roughness; chip compression ratio; optimization; Taguchi

Citation: Gyliene, V.; Brasas, A.; Ciuplys, A.; Jablonskyte, J. Optimization of the Surface Roughness and Chip Compression Ratio of Duplex Stainless Steel in a Wet Turning Process Using the Taguchi Method. *Machines* **2024**, *12*, 437. https://doi.org/10.3390/machines12070437

Academic Editor: Kai Cheng

Received: 4 April 2024
Revised: 11 June 2024
Accepted: 19 June 2024
Published: 26 June 2024

1. Introduction

The attractive combination of high mechanical strength, good corrosion resistance, and a relatively low cost has contributed to making duplex stainless steels (DSSs) one of the fastest-growing groups of stainless steels [1]. Additionally, their usage has increased due to high fracture toughness and high fatigue as compared to plain carbon steels [2]. However, low thermal conductivity, together with high strength and high heat capacity, has made stainless steel a difficult-to-machine material [3]. Moreover, high material strength requires high cutting energy, resulting in high heat generation during machining [2]. Consequently, this poses an increase in tool wear when following the challenges to ensure surface roughness and surface integrity. Moreover, to determine feasible or even advantageous settings for process parameters, handbooks and cutting tool catalogues are available to practitioners to select specific values from a constrained applicable range. However, such recommended ranges for setting process parameters are far from being optimal to satisfy performance metrics [4].

In the past ten years, there has been a noticeable jump in studies on the machining of stainless steels. In order to compare, Koyee et al. [1] summarized the research, emphasizing that the majority of the aforementioned research made very few efforts towards the application of recent modelling and optimization techniques for optimizing the machining of DSSs. Nowadays, the research fields of DSS in turning cover different fields. Thus, Figure 1 represents the most relevant topics from the most cited articles in the past 10 years, revised at the Web of Science [1,3,5–22]. Figure 1 was generated using software VOSviewer 1.6.20 (Copyright © 2009–2023 Nees Jan van Eck and Ludo Waltman). As it is depicted in Figure 1, the main objective, while turning DSSs, is the machinability of this difficult-to-cut material. Consequently, this reveals the challenges of maintaining the tool's life.

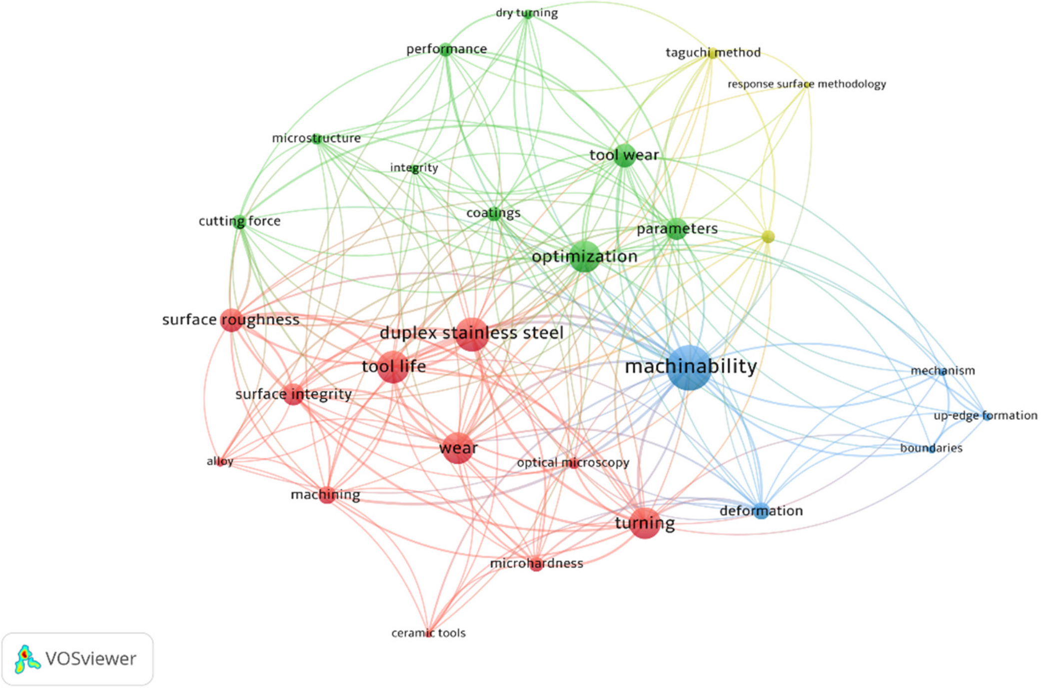


Figure 1. The visualization of main research topics in the field (keywords: turning, duplex stainless steel).

Thus, the inspection and the monitoring of wear is of great importance to ensure the quality of product. Surface roughness is a widely used index of product quality and, in most cases, a technical requirement for mechanical products [23]. Moreover, the quality of the finished part is not only the surface roughness, but also surface integrity. Due to DSS's poor machining property, the surface and subsurface are easily damaged during the machining process [8,9]. Moreover, the process of turning ferritic–austenitic steels at high cutting speeds generates heat [24], and the temperature of the machined material can reach the temperature of transformation [10]. Finally, all factors resulting in an increase in the cutting force cause an increase in hardening [10]. Consequently, after analyzing machining conditions, it was stated that the increase in cutting velocity up to 100 and 150 m/min results in the microhardness gradient reduction, compared to low cutting velocity [10]. Thus, G. Krolczyk et al. [10,11] investigated the changes in microhardness according to different cutting conditions. Accordingly, earlier, G. Krolczyk and S. Legutko [8] stated the two main poles of surfaces integrity, cutting conditions and tool, without emphasizing machines/environment. Nowadays, cutting fluids are widely used to improve the production rate without negatively affecting the machined surface integrity and tool life [25]. However, there is a dilemma between dry, wet, or minimum quantity lubrification (MQL) aimed at cleaner or faster production [26,27]. Tribological characteristics in the dual-jet-MQL-assisted turning of DSS were investigated by M. K. Gupta et al. [15]. M. Dhananchezian et al. [16] investigated the effect of cryogenic cooling on machinability characteristics of DSS.

To sum up, difficult to cut materials are characterized by poor machinability and, consequently, penalized by severe tool wear and poor surface quality [25]. Thus, the main goals when optimizing cutting processes mainly remain the minimization of surface roughness, the minimization of cutting forces [28] or the maximization of the productivity [17]. In this case, the target functions when optimizing cutting conditions are the minimization of tool wear and the maximization of tool life [6]. Consequently, there is a search for technological solutions that would allow part manufacturing in a manner that would make it possible to reliably predict the manufacturing time and the quality of machined parts. Thus, the cutting velocity is the most important parameter, affecting machining time. Additionally, Astakhov and Shvets [29] stated that cutting velocity influences the energy spent on the deformation of the chip through the temperature. According to the mentioned authors [29], the Chip Compression Ratio (CCR) reveals the energy spent on cutting, and the target rule should be applied, namely the smaller the plastic deformation, the better the cutting process. Moreover, Astakhov and Shvets emphasized that CCR is of prime importance in metal cutting studies and process optimization [29]. Consequently, G. Krolczyk et al. [12] emphasized the importance of Specific Cutting Energy (SCE) when processing materials by chip removal. Additionally, the removed material, i.e., chips after machining, is a quantitative response to the performance of a process [30]. In some cases, it is even a mandatory requirement to have a minimum chip thickness to ensure the chip removal process [31,32].

This article presents the investigation of the wet turning of DSS, aiming to minimize the surface roughness and CCR, a rare parameter that is included in the studies of materials' processing. Consequently, the choice of cutting velocity in DoE was beyond conventional range, compared with the parameters that were found in the literature [6,14,21,28,33,34]. Taguchi analysis and the analysis of variance (ANOVA) presented the significance of machining parameters and their percentage of contribution on the response parameters.

2. Materials and Methods

This section is composed of the description of the experimental setup of turning Duplex EN 1.4462 (DIN EN 10088-1) [35] and the design of experiments (DoEs). The experiments are designed by using Taguchi's experimental design method. The experimental data are analyzed by using the signal-to-noise ratio (S/N ratio) and the analysis of variance (ANOVA). The ANOVA analysis is used to find the percentage contribution of the cutting conditions (factors) on response parameters, i.e., surface roughness R_a and CCR.

2.1. *Experimental Setup*

The investigation was performed on two spindle CNC turning center Hass DS 30Y, with a speed rate of spindle up to 4500 rpm. The machine tool was equipped with tool shank of ISO—PDJRN/L 2525M15 (Hoffmann Group, Knoxville, TN, USA)°type and, accordingly, a cutting tool insert DNMG150604-MF1 CP500 (Manufacturer SECO, Fagersta, Sweden) with TiAlN/TiN-PVD coating. The cutting blade was a 55° diamond-shaped positive turning insert with a 0° clearance angle, a 93° entering angle, and a 0.4 mm nose radius. Workpiece material was 1.4462 (DIN EN 10088-1) steel with a ferritic–austenitic structure containing about 50% of austenite. The ultimate tensile strength R_m = 700 MPa and Brinell hardness was 293 HB. The elemental composition is presented in Table 1.

Table 1. Chemical composition of austenitic–ferritic steel 1.4462 (values in wt%, DIN EN 10088-1).

C	Si	Mn	P	S	Cr	Mo	Ni	N
0.03	1	2	0.035	0.015	21–23	2.5–3.5	4.5–6.5	0.1–0.22

The selected turning insert was particularly designated for finishing turning. Thus, the workpiece was turned before finishing turning to prevent radial runout. The workpiece rod of 30 mm in diameter was moved out from three cam chuck up to 30.5 mm in order to perform planning when the experiment was executed according to the design of the experiment; see Figure 2.

(**a**) (**b**)

Figure 2. (**a**) Preparation of the experiment. (**b**) Securing of the turning tool and workpiece.

Conventional lubrification of 7% concentration (Manufacturer Rhenus Lub, Mönchengladbach, Germany) was supplied at the zone of cutting. After turning, the planning operation was executed up to 2 mm in diameter in order to remove the part safely. Accordingly, after each experiment, the chips were collected for further inspection, and each insert was changed, and a new one was fixed with a dynamometer up to 3 Nm in order to have identical cutting tool conditions. Surface roughness of the workpiece was measured by using a profilometer SJ-210 (Manufacturer Mitutoyo, Kawasaki, Japan) according to ISO 1997:4287 standard [36]. Consequently, after the surface roughness evaluation, the machined samples were cut by using an electroerosion machine in order not to impact the surface integrity. In the next step, the preparation of test samples was carried out by using a Smartlam 2.0 polishing machine. These samples were ground using emery papers (180, 800, 1500, 2500 sequentially). The same sequence was applied for the sample preparation in chip thickness evaluation. The hardness of the workpiece material and the hardness beneath the surface were measured by using Innovatest Verzus 750 CCD device (Innovatest Europe BV, Maastricht, The Netherlands) and Mitutoyo Micro Vickers Hardness Testing Machine HM-200 (Manufacturer Mitutoyo). The indentation of the sample was applied according to the stepped path not to harden the neighboring region for the next hardness measurement. This allowed us to measure the hardness variation beneath the machined surface. Additionally, microstructural analysis was performed to investigate the possible transformation of the structure to evaluate the effect of turning as a mini-heat process. Microscope Zeiss AXIO Scope.A1, equipped with a camera ZEISS Axiocam 208 colour and software Labscope 4.2 for Windows (Carl Zeiss Microscopy GmbH, Jena, Germany) were used for precise chip thickness measurements. These acquired data were used for the CCR calculation. Figure 3 depicts the flowchart of the analysis of the output parameters after the experimentation and previously described investigation.

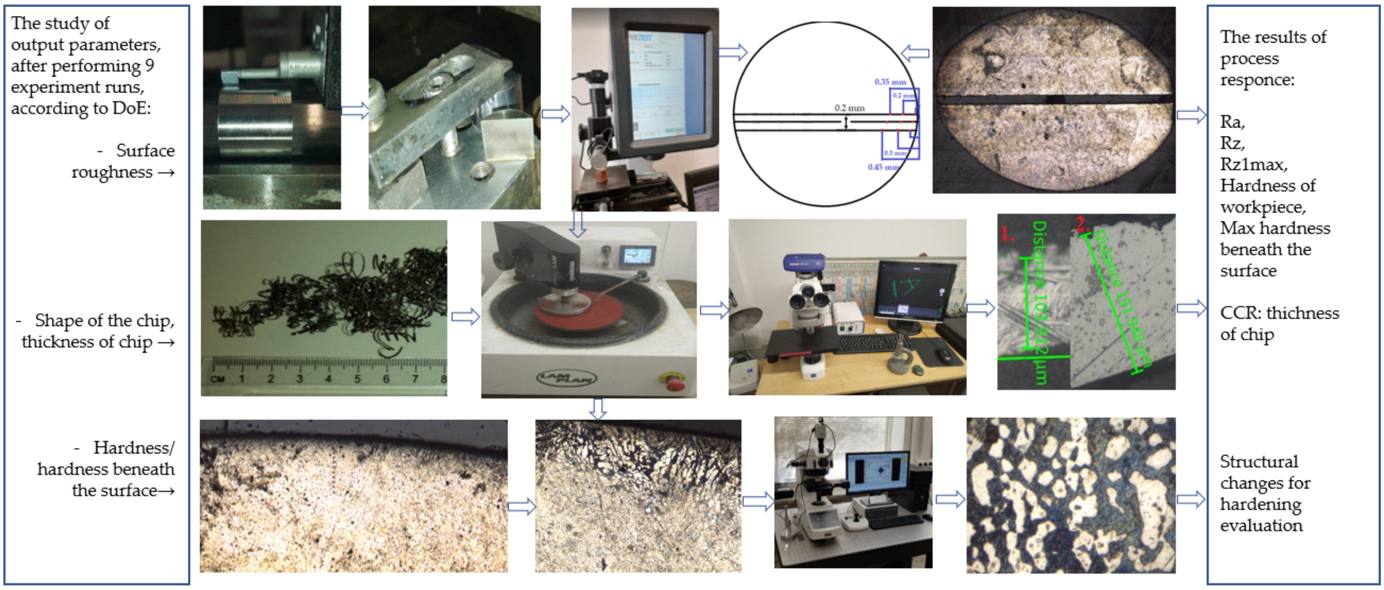


Figure 3. The flowchart of the performed investigation of the machinability of Duplex 1.4462.

2.2. *Design of Experiments*

Taguchi's experimental design method and the ANOVA analysis were employed to analyze the effect of the cutting parameters. Moreover, the Taguchi method allows for the optimization of the system performance and determining the best options of parameters with a reduced number of experiments or analyses rather than a full factorial analysis [37]. It has been found that the performance of machinability is a combination of the tool's geometry, cutting conditions, and environment. Accordingly, the design of the experiment was drawn up under the literature analysis [6,14,21,28,33,34]. After revising the research results of the authors [6,14,21,28,33,34], it has been found that more than 100 experiments were performed when machining DSS. Most of these experiments were performed in a dry environment, and the cutting conditions used in these experiments were in the following ranges: cutting velocity of 50–240 m/min, feed of 0.02–0.6 mm/rev, and cutting depth of 0.3–4.5 mm. The main cutting tool's geometrical parameter, affecting the quality of the machined part, was a corner radius of 0.8–1.6 mm in the presented works [6,14,21,28,33,34], thus resulting in rough machining. Consequently, the presented paper focuses on precise turning by selecting an indexable insert with a corner radius of 0.4 mm. Therefore, the L9 array was formulated for the experimentation, and three levels (ranges) of each parameter were chosen. The parameter levels (cutting conditions) were chosen (Table 2) according to the findings that were presented in the literature review [6,14,21,28,33,34] and aimed to find the order of importance for finishing turning.

Table 2. Cutting conditions levels.

Parameters			Levels		
Description	**Symbol**	**Unit**	**1**	**2**	**3**
Cutting velocity	V_c	m/min	150	200	250
Feed	f	mm/rev	0.05	0.1	0.15
Cutting depth	a_p	mm	0.5	1.0	1.5

Accordingly, Table 3 shows the L9 experiments array and the data on the performed experiment: the time of experiment, the volume of removed material during the experiment, and the material removal rate (MRR).

Table 3. L9 array of experiments and data on the experiment.

Factors				Data of the Experiment		
Run Order	Cutting Velocity (m/min)	Feed (mm/rev)	Cutting Depth (mm)	Time of Experiment (s)	Material Removal Rate (mm³/min)	Volume of Removed Material (mm³)
1	1	1	1	38	3750	2375
2	1	2	2	21	15,000	5250
3	1	3	3	15	33,750	8437.5
4	2	1	2	29	10,000	4833.3
5	2	2	3	17	30,000	8500
6	2	3	1	13	15,000	3250
7	3	1	3	24	18,750	7500
8	3	2	1	15	12,500	3125
9	3	3	2	11	37,500	6875

3. Results and Discussions

This part of the article represents the gathered data and discusses the results of the statistical analysis for the process evaluation of the wet turning of DSSs. Taguchi's experimental design method and the Analysis of Variance (ANOVA) were employed to analyze the effect of cutting parameters on surface finish through surface roughness and surface integrity through the estimation of plastic deformation, taking into account the CCR.

3.1. *Experimental Results*

All turning experiments of DSS 1.4462 were performed with conventional lubrication; according to the DoE presented in Table 3, these experiments generated continuous chips. Their shape, after turning experiments, is presented in Figure 4.

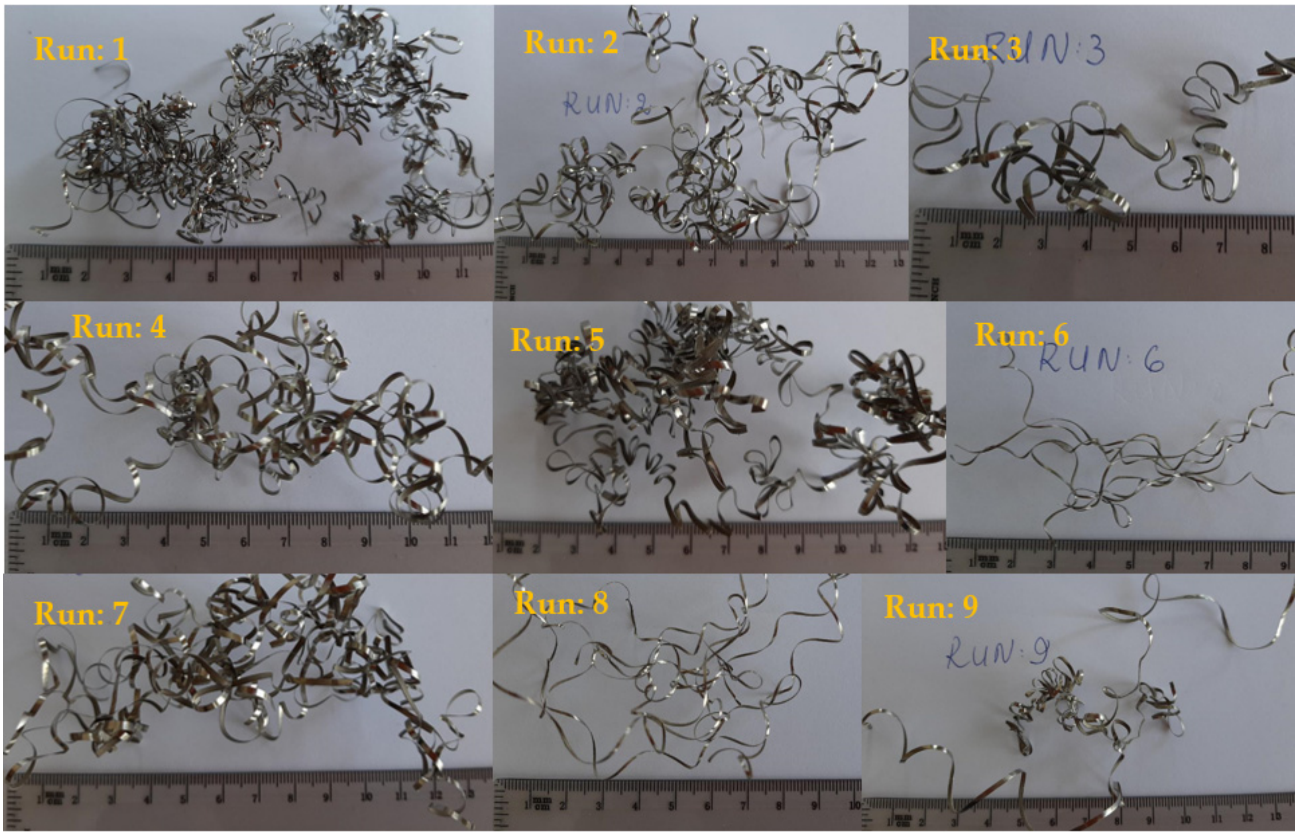


Figure 4. Collected chips after the experiments.

The chip compression ratio represents the true strain in plastic deformation and should be used to calculate the elementary work spent over the plastic deformation of a unit volume of the work material [29]. The simplest method to measure the chip thickness and then calculate CCR is by employing the following formula:

$$\xi = t_2/t_1, \tag{1}$$

where t_2 is the chip thickness and t_1 is the uncut chip thickness [29].

Moreover, the chip compression ratio or chip reduction coefficient is widely considered as an index of machinability [18]. The greater value of CCR indicates more chip thickness, and hence, greater energy required for machining [18]. Additionally, CCR can be used for the evaluation of the effect of the insert's coating, as performed by Parsi et al. [18], but the mentioned authors applied low-cutting velocity. Consequently, Figure 3 represents the measured real chip thickness measurements for the CCR calculation. All output results after the experimentation are presented in Table 4. This table contains the measured surface roughness parameters, chip thickness evaluation parameters, and the results of the hardness measurements. The variation of hardness beneath the surface was measured up to 0.5 mm, and the defined maximum hardness value is presented in the table below. Feed is the most influential parameter affecting the thickness of the chip and, consequently, CCR. All measured surface roughness parameters are presented in Table 4 as well. The most common surface roughness parameter R_a (average surface roughness), used in the evaluation of part quality in metal cutting, is used in statistical analysis.

Table 4. Experimental results.

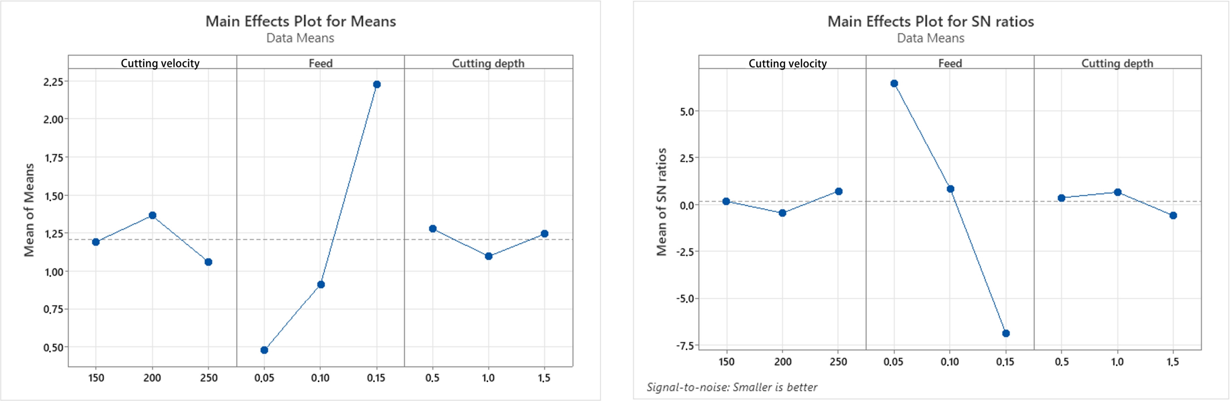
Cutting Conditions				Output Results					
Run	**Cutting Velocity**	**Feed**	**Depth of Cut**	**Surface Roughness**			**Chip Evaluation**		**Max Hardness**
	m/min	**(mm/rev)**	**(mm)**	R_a **(µm)**	R_z **(µm)**	R_{z1max} **(µm)**	**Thickness (µm)**	**(CCR)**	**HV**
1	150	0.05	0.5	0.448	3.177	3.373	105.2	2.1	241.4
2	150	0.1	1	0.974	5.696	6.502	189.05	1.9	266
3	150	0.15	1.5	2.155	10.483	11.056	277.4	1.85	235
4	200	0.05	1	0.433	3.133	3.512	116.7	2.33	256.2
5	200	0.1	1.5	1.023	6.375	8.009	164.7	1.65	277.1
6	200	0.15	0.5	2.637	11.993	12.854	208.33	1.39	260.7
7	250	0.05	1.5	0.554	3.936	4.497	98.24	1.97	248
8	250	0.1	0.5	0.746	4.41	5.098	160.7	1.61	248
9	250	0.15	1	1.885	10.473	12.541	238.6	1.59	280

3.2. Taguchi Analysis

Minitab Statistical Software 22.1.0 (x64) was used to perform the statistical analysis. In the first part of the statistical analysis, the Taguchi method was applied to find out the influence of process parameters and evaluate the importance order for the minimization of the surface roughness and CCR accordingly (output results of experiments, presented in Table 4). Secondly, the impact ratio for each parameter was determined by using ANOVA analysis. According to Taguchi analysis, the results of the target functions were converted to the S/N (signal-to-noise) ratio. S/N ratio calculation was done by applying the performance characteristic "Smaller is better." The formula for the smaller-the-better signal-to-noise (S/N) ratio is given in Equation (2), which is a measure of the variation in the output quality characteristic (signal) relative to the variation due to other factors (noise). By minimizing the variation in the output quality characteristic, the S/N ratio is increased, leading to higher quality and lower costs [38]. The smaller-the-better S/N ratio (minimization) is calculated as follows:

$$S/N = -10\log\left(sum(y^2)/n\right) \quad (2)$$

The previously presented assumption that "Smaller is better" was applied for both output responses, i.e., R_a and CCR. Firstly, in the presented study, smaller surface roughness is an indication of better product quality. Secondly, the smaller the plastic deformation, the higher the process efficiency because, according to Astakhov and Shvets, plastic deformation should be reduced [29]. Thus, in order to find the optimum machining parameters, the highest S/N ratio of the cutting condition levels indicates the best factor levels. The best factor levels on surface roughness R_a of the performed experiments are shown in the main effects plot for means (Figure 5a) and S/N ratios (Figure 5b).



(**a**) (**b**)

Figure 5. Taguchi analysis results: the influence of process parameters on R_a. (**a**) Main effects plot for means; (**b**) Mean of S/N ratio.

The best parameter levels are indicated by the minimum part of the line in the main effect plot for the means graph and the maximum part of the line in the main effect plot for the S/N ratio graph. Thus, the optimum cutting conditions on surface roughness are as follows: V_c (level 3: 250 m/min), f (level 1: 0.05 mm/rev), and a_p (level 2: 1 mm), as presented in Table 5.

Table 5. Optimum cutting conditions: minimization of surface roughness R_a.

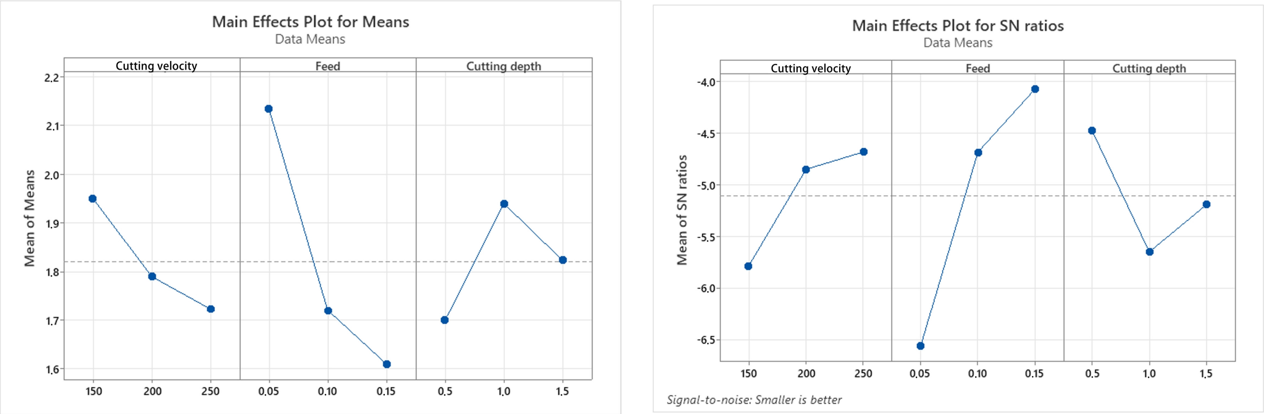
Run:	**Cutting Conditions**		
	Cutting Velocity (m/min)	**Feed (mm/rev)**	**Cutting Depth (mm)**
Prediction	250	0.05	1

The calculation of the S/N ratio allows for the rating of cutting parameters according to the order of significance. As it is presented in Table 6, it has been found that the feed had the highest effect on the surface roughness R_a. Accordingly, the effect of cutting velocity and cutting depth was quite equal within the smallest effect of cutting velocity in the performed range of machining parameters.

Table 6. The effect of cutting parameters on surface roughness R_a through S/N response.

Level	V_c	f	a_p
1	0.1781	6.4582	0.3658
2	−0.4498	0.8588	0.6643
3	0.7229	−6.8658	−0.5789
Delta	1.1728	13.3240	1.2432
Rank	3	1	2

Analogously, the best factor levels on the CCR of the performed experiments are shown in the main effects plot for means (Figure 6a) and the S/N ratio (Figure 6b).



(**a**) (**b**)

Figure 6. Taguchi analysis results: the influence of process parameters on CCR. (**a**) Main effects plot for means; (**b**) Mean of S/N ratio.

Thus, the optimum cutting conditions on CCR are as follows: V_c (250 m/min at level 3), f (0.15 mm/rev at level 3), a_p (0.5 mm at level 1), as presented in Table 7.

Table 7. Optimum cutting conditions: minimization of CCR.

Run:	**Cutting Conditions**		
	Cutting Velocity (m/min)	**Feed (mm/rev)**	**Cutting Depth (mm)**
Prediction	250	0.15	0.5

As it is presented in Table 8, it has been found that the feed had the highest effect CCR. Accordingly, the cutting depth had the secondary effect, quite equal, within the smallest effect of cutting speed on the performed range of machining parameters.

Table 8. The effect of cutting parameters on CCR through S/N response.

Level	V_c	f	a_p
1	−5.788	−6.560	−4.480
2	−4.852	−4.687	−5.650
3	−4.685	−4.077	−5.194
Delta	1.103	2.483	1.170
Rank	3	1	2

It is worth mentioning that the Taguchi method, a robust statistical design method, has been used for the optimization, with a reduced number of experiments. An alternative method used to optimize the process is the response surface methodology (RSM) based on central composite design, which requires a larger number of experiments than the Taguchi method, but offers a more advanced statistical analysis of the results [39].

3.3. Analysis of Variance

ANOVA analysis was applied to analyze the significance of cutting conditions on surface roughness R_a and CCR. The means μ_1, μ_2, μ_3 are the cutting velocity, feed, and cutting depth, respectively. In order to check the significance level, the hypothesis needed to be verified. It is assumed that $H_0: \mu_1 = \mu_2 = \mu_3$, and, respectively, H_1: at least two means are different. The confidence interval in the field of machining is 95%. Thus, in this study, the p-value is taken at a level of 0.05. Using technology, the value of statistics F-value and p-value are given in the table of the analysis of variance for S/N ratios. As p-value ≥ 0.05, H_0 hypothesis is accepted; otherwise, there is enough evidence to reject H_0 hypothesis in favour of H_1 on a 5% significance level. The same one shows statistic F values. Thus, this is confirmed by the statistic F, as F $\geq$ F_{crit} (4.459) when rejecting H_0. To conclude, there is a significant difference between means. The detailed significance of factors on the surface roughness and CCR is presented in Tables 9 and 10.

As it can be seen from Table 9, p-value is compared; if it is a smaller value than 0.05, the factor is statistically significant, and if the p-value is more than 0.05, it is statistically unimportant at a 95% confidence level. Thus, it has been found that the feed is a statistically significant parameter with a contribution of 95.94% for surface roughness R_a.

Table 9. The results of analysis for S/N ratios: surface roughness R_a.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)	Significance
Cutting velocity	2	2.066	2.066	1.033	0.31	0.766	0.74	Non-significant
Feed	2	268.550	268.550	134.275	39.71	0.025	95.94	Significant
Cutting depth	2	2.527	2.527	1.263	0.37	0.728	0.903	Non-significant
Residual Error	2	6.763	6.763	3.382				
Total	8	279.907						

Accordingly, it can be seen from Table 10 that the analysis does not present statistically significant parameters for CCR; nevertheless, the percentage of the contribution rate of feed is 65.14%.

Table 10. The results of analysis for S/N ratios: CCR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)	Significance
Cutting velocity	2	2.120	2.120	1.0598	1.81	0.356	13.74	Non-significant
Feed	2	10.046	10.046	5.0232	8.59	0.104	65.14	Non-significant
Cutting depth	2	2.085	2.085	1.0427	1.78	0.359	13.52	Non-significant
Residual Error	2	1.170	1.170	0.5850				
Total	8	15.421						

According to the Taguchi analysis, the variation of data for surface roughness analysis could be explained according to a linear model, with a high R-Sq value of about 98%. Additionally, the variation of data for CCR analysis could be explained according to the linear model, with a high R-Sq value of about 92%. Table 11 summarizes the variation of data according to the linear models.

Table 11. Data linear models' summaries.

Taguchi Analysis: Surface Roughness R_a			Taguchi Analysis: CCR		
S	R-Sq	R-Sq(adj)	S	R-Sq	R-Sq(adj)
1.8389	97.58%	90.33%	0.7648	92.41%	69.65%

As it was found, different techniques like dry, minimum quantity lubrication (MQL), chilled air, compressed cold air, gas cooling, air cooling, high-pressure cooling (HPC), and solid coolants/lubricants were used to minimize adverse effects during machining [26,27]. However, the application of conventional lubrification provided a better-quality machined surface (R_a equal to 0.443 μm), which was attained by applying cutting conditions beyond the conventional range. Experimental results showed that machining parameters' cutting velocity was equal to 200 m/min, the feed was equal to 0.05 mm/rev and the cutting depth of 1 mm allowed us to achieve the best surface roughness $R_a = 0.443$ μm. The usage of a smaller nose radius or type of machining environment allowed us to ameliorate surface roughness 0.1–0.2 μm, when comparing results [6,14,21,28,33,34]. Thus, the primordial point becomes the selection and optimization of cutting conditions.

Moreover, the study showed that the usage of cutting conditions beyond the conventional range with conventional lubrification allows us to achieve a smooth surface. Cutting velocity of 250 m/min (respectively, $f = 0.05$ mm/rev, $a_p = 1.5$ mm) allows us to achieve $R_a =$ 0.554 μm (time of machining: 24 s; CCR = 1.97). Cutting velocity of 250 m/min (respectively, $f = 0.1$ mm/rev, $a_p = 0.5$ mm) allows us to achieve $R_a = 0.746$ μm (time of machining: 15 s; CCR = 1.61). The highest cutting velocity of 250 m/min and the highest feed of 0.15 mm/rev (respectively, $a_p = 1$ mm) allows us to achieve $R_a = 1.885$ μm (the shortest time of machining: 11 s; CCR = 1.59). The increase in cutting velocity positively impacted CCR, or the so-called machinability index, by decreasing this parameter. Although, the significance of cutting velocity was not confirmed by statistical analysis. The results revealed that, nevertheless, the application of conventional lubrification allows for faster and cleaner machining. Moreover, the study showed that there is still a gap in research on DSS, particularly in terms of collecting quite a big amount of data for the prognostic study by using artificial intelligence techniques.

4. Conclusions

The Taguchi optimization method was successfully used to identify the optimal cutting parameters duplex stainless steel 1.4462 during wet turning finishing operations. The main goal of the experiments, according to L9 Taguchi DoE, was to examine the surface roughness R_a and CCR. DoE was realized with a TiAlN/TiN-PVD coating insert, with a nose radius of 0.4 mm and up to 250 m/min cutting velocity. The following has been found:

- A cutting velocity of 200 m/min, feed of 0.05 mm/rev, and cutting depth of 1 mm are found to give the lowest surface roughness R_a that is equal to 0.433 μm;
- A cutting velocity of 200 m/min, feed of 0.15 mm/rev, and cutting depth of 0.5 mm are found to give the smallest CCR that is equal to 1.39, indicating the smallest plastic deformation during the material removal process;
- The experimental results proved that additional cooling allows us to achieve better surface roughness quality compared to dry and wet turning;
- The experimental data could be useful in collecting as much data as possible for the use of artificial intelligence techniques, i.e., for the training and validation of models; the lack of data provides overfitted models.

Author Contributions: Conceptualization, V.G. and A.C.; methodology, V.G. and A.C.; software, V.G. and J.J.; validation, V.G., A.B., A.C. and J.J.; formal analysis, V.G. and A.B.; investigation, V.G.; A.B. and A.C.; resources, V.G. and A.B; data curation, A.B., A.Č. and J.J.; writing—original draft preparation, V.G.; writing—review and editing, V.G., A.C. and J.J.; visualization, V.G., A.B. and A.C.; supervision, V.G.; project administration, V.G.; funding acquisition, V.G., A.C. and J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The department of Transport Engineering partially covered the fee of APC.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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