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Investigation of the Effects of Cutting Parameters on Diameter Deviation in Drilling of HSLA Steel

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ABSTRACT In this study, effect of cutting parameters on the diameter deviation was experimentally investigated in drilling of high strength low alloy (HSLA) material. In the experiments, TiAlN coated and uncoated drills with a diameter of 8 mm and 130 ° point and 30 ° helix angle were used. Three different feed rates (0.05-0.075-0.1 mm / rev) and cutting speed (10-26-42 m / min) were determined as cutting parameters. As a result of the study, it was found that in the experiments with both cutting tools, the diameter deviation increases with the increase of the feed rate and cutting speed and the TiAlN coated drills perform better than the uncoated drills.

Keywords: Drilling, HSLA, Diameter Deviation, ANOVA

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1. INTRODUCTION

High-strength low-alloy (HSLA) steels are defined by microstructures formed by hard martensite particles distributed in the ductile ferrite matrix [1-2]. These steels are compared to dual phase steels due to their behavior of constant flow, high deformation hardening, high malleability, and the opportunity of obtaining good surface quality [3-4]. These materials contribute to rigidity and strength and reduction of weight without losing strength, and therefore are preferred in automotive industry. As their formability characteristics are good, they play an effective role in production of parts in vehicles such as suspension systems, support elements, longitudinal girders, cross and chassis components [5-6].

Drilling, on the other hand, is one of the most frequently used processes in manufacturing and it constitutes approximately 33% of machining [7-8]. Additionally, 25% of the entire manufacturing process consists of drilling [9]. Drilling is usually the last of the machining processes and it has great importance in economical nature of production [10]. In comparison to turning and milling processes, it has similar kinematics and dynamic structure and the debris flow, cutting temperature, weight distribution are similar in the time of cutting. However, the occurrence of debris in the process of drilling in an enclosed environment makes debris management more difficult. The thickness of debris that is formed on the drill is the factor that affects debris flow. The main problem in drilling is that the surface temperature that occurs on the surface based on friction between the drill and the material is insufficient and the cutting speed in the rotation axis is zero. Thus, there are various attempts in the literature regarding with improvements of surface coating processes, drill geometry and materials [9-11].

Developments in machining have resulted in improvements in cutting speeds and feed rates, usage of various materials in production, machine tools and tool sets. The cutting characteristics of HSS tools have been improved to a significant extent nowadays. Optimal combinations of alloying elements of cutting tools and heat processes contributed not only to optimal hardness and toughness, but also give increase in abrasion resistance [12]. One of the most important technological advantages in developing modern cutting tools is the hard coatings applied on cutting tools [13]. Coatings on cutting tools play an important role in increasing their abrasion resistance by reducing the friction on the surface between the cutting tool and chip [14].

In machining, obtaining desired surface quality in drilling processes is one of the most important issues. It is very difficult to achieve measurement accuracy on a hole drilled with a drill directly. Due to these issues, it is generally popular to use boring and reaming as secondary processes [15]. Nevertheless, a secondary process to be applied on the material leads to increases in cost. Accordingly, it is crucial for a hole to be drilled in one operation for the desired measurement accuracy. It was seen that most of the studies in the literature are dedicated to hole surface quality and measurement accuracy (deviation from diameter, circularity and cylindricality). Özkul et al. promoted usage of low cutting speeds for optimal values of diameter deviation and circularity while drilling hot work steels with reamed and carbide drills [16], while Yağmur et al. [17] suggested using low cutting speeds in drilling AISI 1050 steel with TiN/TiAlN/TiCN multi-layer coated and non-coated carbide drills to minimize vibrations, and they stated that cutting forces of coated tools are reduced due to reduced friction, and therefore, lower values of deviation from circularity may be achieved. Kıvak et al. [18], investigated the drilling of AISI 316 stainless steel with HSS drills processed with different coating operations (one-layer TiN and TiAlN, and multi-layer TiAlN/TiN), and they stated that cutting speed is a more effective factor than progression. In addition, they noted that drills coated with TiAlN/TiN had a better performance than those with other coating processes. Moreover, other studies have been conducted, where hole measurement sensitivity could be estimated based on cutting parameters, and mathematical modelling and statistical methods were used [19-20]. Furthermore, the literature also contains studies on the effects of drill diameters [21] and workpiece materials [22-23] on the hole measurement sensitivity.

In this study investigated the effects of cutting parameters on deviation from hole circularity was investigated using three different feed rates (0.05-0.075-0.1 mm/rev) and cutting speeds (10-26-42 m/min) while drilling HSLA material with TiAlN coated and uncoated HSS drills.

2. MATERIAL AND METHOD

The drilling experiments were carried out at Johnford VMC 850 CNC vertical machining center which has a capacity of 6.000 rev/min and 7.5 kW power. As cutting tools, TiA1N coated and uncoated HSS drills were acquired from Walter Corp. (Tübingen, Germany) were used. Technical characteristics of the drills used in the experiments are given in Table 1.

Table 1. Technical characteristics of cutting tools used in experiments

Cutting Tool	Coating type	Coating thickness (μm)	Number of flutes	Point angle	Helix angle	Helix length (mm)	Cutting tool image
Uncoated HSS tool	-	-	2	130º	30º	24	
Coated HSS tool	TiAlN	3	2	130º	30º	24	

As the workspace, HSLA-DIN EN 10149 high-strength low-alloy material, which is widely used in the automotive industry, was used. The chemical composition and physical characteristics of the material used in the experiments are given in Table 2 and Table 3, respectively [24].

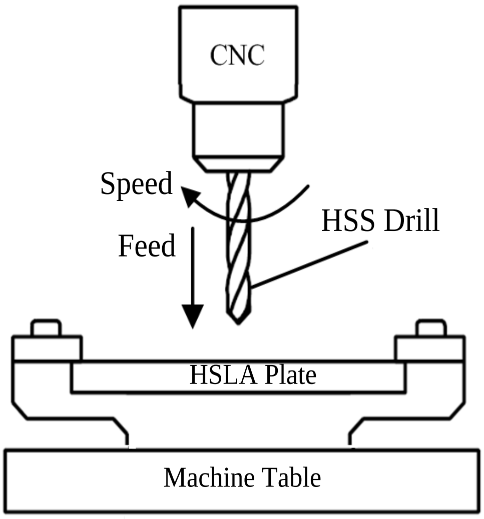
Table 2. Chemical composition of HSLA material (% max.)

C	Si	Mn	P	S	Al	Nb	Ti	V	Fe
0.12	0.50	1.50	0.025	0.020	0.015	0.09	0.15	0.20	Other

Table 3. Physical properties of HSLA material

Tensile strength (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Pulse energy (J)	Pulse temperature (^oC)
430-550	355	23	40	-20

The drilling experiments were carried out with coolant (Hocut 3380-20% emulsion) using the set up schematic shown in Figure 1(a). Diameter deviation values were determined as arithmetic average by taking measurements from five different points via a DEA model of product (Hexagon, Germany) brand three-dimensional CMM (Coordinate Measurement Machine) device is shown in Figure 1(b).



(a)

(b)

Fig. 1. a) Schematic of the experimental setup, b) View of CMM device

2.1. Experimental Design

In this study, Taguchi method was used for experimental design and analysis. This method is useful for both analyzing interactions among variables and in terms of costs- effectiveness [25-26]. In experimental studies, values obtained from the objective function are converted into signal/noise (S/N) ratios in order to determine the performances of levels belonging to control factors against uncontrollable factors [27]. In determining the S/N ratio, "smaller the better, bigger the better, nominal is best" objective functions are used. ANOVA (Analysis of Variance) is used to determine whether independent variables are statistically significant or not. In this way, optimization validity is determined by conducting confirmation tests after determining the optimum conditions with the help of S/N ratios and ANOVA [28]. In this study, optimization for cutting parameters to achieve minimum diameter deviation in drilling HSLA materials was carried out. Cutting parameters were determined by conducting three preliminary experiments for same parameters. Besides, cutting speed (m/min) and feed rate (mm/rev) were determined as the independent variables and three different levels were fixed for each independent variable. As the experimental design Taguchi's L_9 (3^2) orthogonal experimental scheme was used. The independent variables and levels of these variables are given in Table 4.

Table 4. Independent variables and levels

Variances	Control factors	Symbol	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	*V*	10	26	42
B	Feed rate (mm/rev)	*f*	0.05	0.075	0.1

In determining the optimal levels of independent variables, it is desired that the diameter deviation is minimized. Therefore, the objective function with "smaller the better" for the performance characteristic was used to determine the S/N ratios in Equation 1.

$$S/N_{SB} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} Yi^2\right) \quad (1)$$

For the experimental results, the level of effects of the independent variables on diameter deviation were determined by using of ANOVA at a 95% confidence interval (α=0.05).

3. EXPERIMENTAL RESULTS

Table 5 shows the diameter deviation (Dd) measured as a result of the drilling operation performed with HSLA material based on the L_9 orthogonal experimental design. It also shows the calculated S/N values based on "smaller the better" objective function of Taguchi.

Table 5. According to Taguchi L_9 orthogonal array experimental results and S/N ratios

Order	A	B	Uncoated HSS drill		TiAlN coated HSS drill	
	1	2	D_d (mm)	S/N (dB)	D_d (mm)	S/N (dB)
1	10	0.05	0.013	37.721	0.01	40.000
2	10	0.075	0.016	35.917	0.014	37.077
3	10	0.1	0.02	33.979	0.018	34.894
4	26	0.05	0.016	35.917	0.015	36.478
5	26	0.075	0.019	34.424	0.017	35.391
6	26	0.1	0.023	32.765	0.021	33.555
7	42	0.05	0.019	34.424	0.016	35.917
8	42	0.075	0.02	33.979	0.018	34.894
9	42	0.1	0.025	32.041	0.023	32.765

The diameter deviation (Dd) and S/N plots measured as a result of the drilling operations carried out with TiAlN coated and uncoated drills for each cutting speed based on feed rate are given in Figure 2.

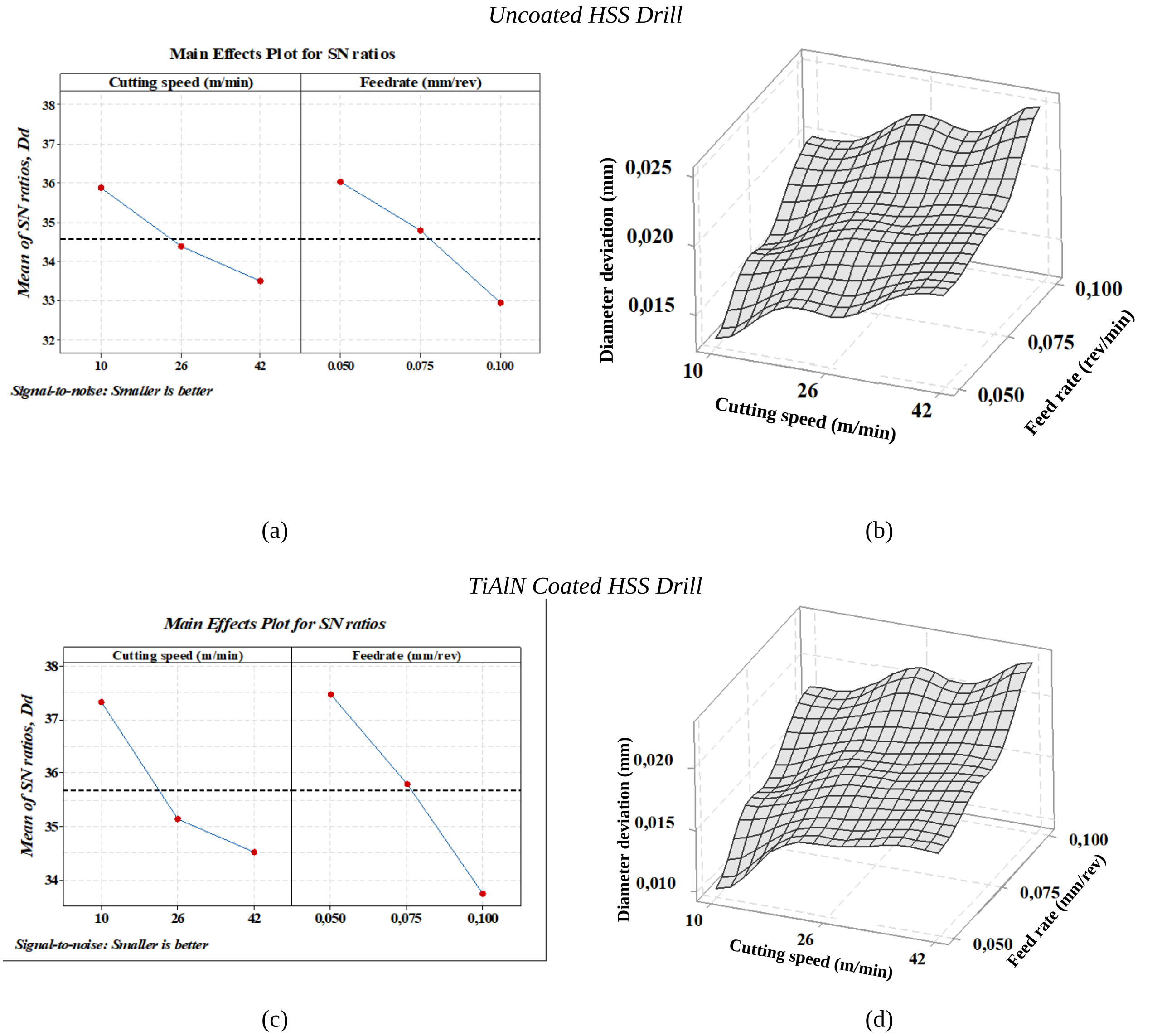


Fig. 2. S/N ratios and diameter deviations for the drilled holes, a) S/N ratios for uncoated HSS drills, b) Effect of feed rate and cutting speed on diameter deviation for uncoated HSS drills, c) S/N ratios for TiAlN coated HSS drills, d) Effect of feed rate and cutting speed on diameter deviation for TiAlN coated HSS drills.

Considering Figure 2. a-c, the optimum parameters for diameter deviation in the drilling processes with uncoated and TiA1N coated HSS drills were found as A_1 (10 m/min) and B_1 (0.05 mm/rev). In Figure 2. b-d, it was observed that diameter deviation increased along with the increases in feed rate. This is caused by the increase in the chip cross-section removed per unit time [24] and the loads occurring on the cutting tools due to the pressure [29-30]. Additionally, it was seen that diameter deviation also increased in line with the increased cutting speed (Figure 2. b-d). This increase in diameter deviation is considered to have been resulted from the effects of high cutting speeds on vibrations that occur during cutting [17]. While friction increased between cutting tool and work piece with increasing cutting speed, idle machining time decreased [31]. When cutting tools are analyzed, it was observed that diameter deviation measured for TiA1N coated tools was lower than that those for uncoated tools. Low friction of the coated tools made the cutting process relatively easier and in parallel with this, forces experienced during cutting also decreased. This situation leads to lower values of diameter deviation with TiA1N coated tools as it was also reported in literature [17].

3.1. Analysis of Variance (ANOVA) Results

Table 6 shows the ANOVA results calculated to determine the effects of the independent variables on diameter deviation for uncoated and TiA1N coated HSS drills. $P<0.05$ was accepted as the level of statistical significance. Accordingly, based on Table 6, the most important factor on diameter deviation was feed rate in both uncoated and TiA1N coated HSS drills by 61.490 % and 60.147 %, respectively. The effect of cutting speed, on the other hand, for uncoated and TiAlN coated HSS drills was found as 37.104 % and as 37.325 %, respectively. The abbreviations in Table 1 are Degree of Freedom (DF), Sum of Squares (SS), Means of squares (MS), and Percentage contribution (PC) respectively.

Table 6. ANOVA results for diameter deviation

Source	DF	SS	MS	F	P	PC (%)
Uncoated HSS Drills						
Cutting speed (m/min)	2	8.764	4.382	26.40	0.005	37.104
Feed rate (mm/rev)	2	14.524	7.262	43.76	0.002	61.490
Error	4	0.663	0.166			1.406
Total	8	23.952				100
TiAlN coated HSS drills						
Cutting speed(m/min)	2	12.972	6.485	14.76	0.014	37.325
Feed rate (mm/rev)	2	20.902	10.450	23.78	0.006	60.147
Error	4	1.758	0.439			2.528
Total	8	35.631				100

Three further experiments were conducted for the optimum levels determined for each type of cutting tools in order to test the accuracy of the experiment results. The results of confirmation experiments were reported by taking the arithmetic mean of the results obtained from experiments. Accordingly, Table 7 shows that the optimization process was successful considering the results of confirmation experiments.

Table 7. Optimum and verification results for diameter deviation

Taguchi Optimization	Uncoated HSS drills		TiAlN coated HSS drills	
	Predicted	Verification	Predicted	Verification
Levels	A1B1	A1B1	A1B1	A1B1
Cutting conditions	10 / 0.05	10 / 0.05	10 / 0.05	10 / 0.05
Diameter deviation (mm)	0.013	0.016	0.010	0.012

4. CONCLUSIONS

In this study, a high strength low alloy (HSLA) material was drilled using uncoated and TiA1N coated HSS drills, and the effects of cutting parameters on diameter deviation were investigated. The main outcomes from the study can be summarized as follows;

- Diameter deviation was lower with TiAlN coated drills than that with uncoated drills,
- Diameter deviation increased in line with increased cutting speeds in both TiAlN coated and uncoated tools,
- Feed rate had a greater effect on diameter deviation with both types of cutting tools,
- The optimum level of cutting speed and feed rate were determined as A_1 (10 m/min) and B_1 (0.05 rev/min), respectively in both cutting tools,
- It was determined that the optimization was successful in the light of the data obtained as a result of confirmation experiments.

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