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FINISHING TREATMENT OF MARINE PUMP SHAFTS MADE OF X5CRNI18-10 STEEL

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Abstract

One of the greatest problems of modern production techniques is the achievement of an appropriate quality at minimal costs and accompanied by the production efficiency increase. Therefore, while designing the production process, the technology used should have a considerable influence on the durability and reliability of machine parts to be produced. During finish treatment, the final dimensions as well as functional properties are imparted to a given element by application of proper treatment type. The engineer has a range of production techniques to choose for the proper surface layer formation. It is crucial to find a suitable solution which will meet the requirements as well as the work conditions of a given machine part. The article presents the results of influence of cutting parameters change on temperature and cutting forces during turning process of stainless steel. A shaft made of 304L stainless steel was used for the research. The cutting process was carried out on a universal CDS 6250 BX-1000 centre lathe. Measurement of cutting forces during lathing process used DKM 2010 turning dynamometer. The turning process was conducted by a cutting tool with CCET09T302R-MF insert by DIJET. During the turning, the following machining parameters were used: cutting speed V_c = 152, 219, 304 m/min, feed f = 0.044, 0.062, 0.083 mm/rev and cutting depth a_p = 0.4, 0.8, 1.2, 1.6 mm. The view of the nose radius of cutting tool before and after the turning process was made by the Smartzoom 5 microscope.

Keywords: *turning dynamometer, temperature and cutting forces, stainless steel*

1. Introduction

Vessels and warships are equipped with main propulsion engines, generating sets and auxiliary machinery, which are used in the engine room as well as on deck. Seawater pumps belong to a group of centrifugal angular momentum pumps. This kind pumps are utilized in the cooling system of high and medium speed engines, for supplying boilers, in bilge systems, ballast systems and in firefighting installations. During their service, the wear of pump body, rotor, sealing, and shaft takes place. The research work made an effort to improve the shafts service durability and it was based on carrying out tests for contact fatigue, friction wear, and electrochemical corrosion. Due to hard service conditions, marine pumps working in seawater environment are made of corrosion resistant materials. In spite of the fact that pump shafts are made of an expensive material, it is not possible to avoid service damage. This damage includes cracking, plastic deformation, excessive wear of pins in places of mounting rotor discs and sealing chokes, corrosive wear, friction wear, erosive wear and spline ways knock outs. During service experience, the most common problem that is observed is excessive wear of pins causing their diameter decrease as well as exceeding the permissible shape deviations in place of chokes mounting.

For the basic method of the surface layer, forming of shaft pins is known lathing. Conventional machining accuracy is usually considered as a function of the characteristics of all the components of machine tool, fixture, object, and tool. There are accuracy performance and the accuracy of static and dynamic determining and cutting parameters, which are associated with strength, temperature, and wear of the cutting edge. Therefore, stock removal of high efficiency should be performed in a controlled manner, which ensures the correct shape and size of the chip.

Many scientific centres, including Gdynia Maritime University, deal with issues related to the turning surface of the difficult-to-machine [1, 2, 4-13]. The research aims to determine a set of input factors, fixed and distorting for the finish lathing of pins shafts made of stainless steel, had an impact on geometrical structure of the surface, as well as on the values of forces and cutting temperature. Machining stainless steels, especially austenitic steel, causes many difficulties. On the machinability of austenitic steel has a negative impact high propensity to the deformation strengthening, low thermal conductivity, and good ductility. Alloying element improves the machinability of stainless steels is sulphur. Sulphur in combination with manganese forms MnS manganese sulphide, which positive influence on machinability is confirmed by the type of chips (short and brittle), smoother surfaces of workpieces and less tool wear.

The article presents the results of influence of change of treatment conditions during turning process of shafts on the temperature and cutting forces for the selected range of cutting parameters.

2. Research methodology

During the research of temperature and cutting forces the shafts made of stainless steel was used (Fig. 1a). The process of turning was carried out on a universal CDS 6250 BX-1000 lathe centre. The lathing process was conducted by a cutting tool with CCET09T302R-MF insert. During the lathing, the following machining parameters were used: cutting speed (V_c), feed (f) and depth of cut (a_p). The value of cutting parameters is presented in Tab. 1.

Tab. 1. The cutting parameters used in turning process

Cutting parameters	
Vc [m/min]	152, 219, 304
f [mm/rev]	0.044, 0.062, 0.083
ap [mm]	0.4, 0.8, 1.2, 1.6

DKM 2010 is a 5-components tool dynamometer for use on conventional or CNC lathe machines. It measures force on the cutting tool up to 2000 N with a resolution of 0.1% and as option also temperatures on the tool tip between 300 and 800ºC. DKM 2010 is equipped with adjustable inserts – holder to change entering angle $\varkappa_r$ into 45, 60, 70, 90º. The equipment of DKM 2010 is presented in Fig. 1b. The view of the nose radius of cutting tool before and after the turning process was made by the Smart zoom 5 microscope (Fig. 1c).

a)

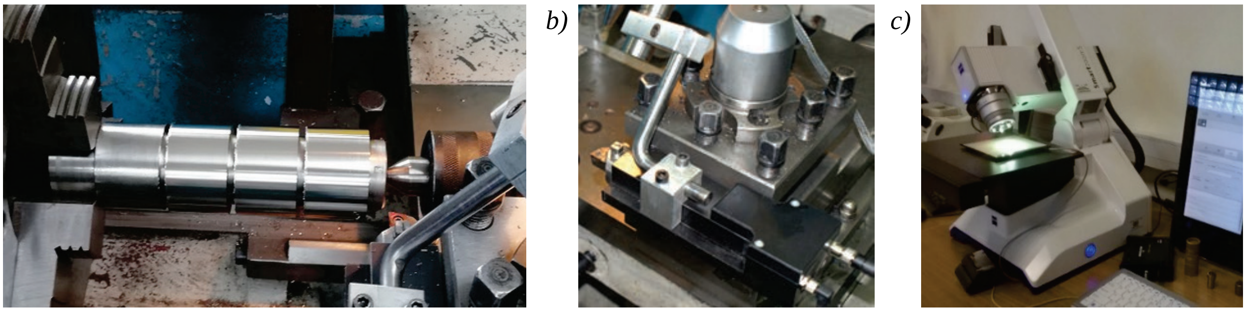

Fig. 1. a) The sample used for turning process, b) DKM 2010 turning dynamometer, c) Smart zoom 5 microscope

Austenitic steels containing 8% Ni have the preferred combination of machinability, mechanical properties, and corrosion resistance. They are the most important group of corrosion resistant steels and have a significant share in the production of stainless steels. Machining of stainless steels is classified as group of materials difficult to machining process [2].

3. Research results

Table 3 shows the results of the basic statistical analysis of the measurement of F_c, F_f, F_p forces, and temperature for cutting speed equal 152 m/min. The highest mean value of force F_c (615 N) was obtained for a cutting depth equal 1.6 mm and feed 0.062 mm/rev.

Tab. 3. The results of statistic analysis of cutting forces and temperature for V_c = 152 m/min

V_c = 152 m/min								
f_n = 0.044 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	97	60	63	388	369	555	59	540
Minimum	63	17	15	331	305	421	46	470
Maximum	168	184	208	500	393	611	79	600
Stand. dev.	35.8	57.7	74.2	49.1	16.7	54.6	6.1	19.0
Stand. error	1.49	2.41	3.10	2.05	0.72	2.35	0.26	0.81
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	438	703	29	543	519	782	7	513
Minimum	400	568	5	456	477	657	0	340
Maximum	489	777	52	624	569	889	34	675
Stand. dev.	18.6	26.5	8.9	25.4	15.8	35.6	8.0	59.9
Stand. error	0.80	1.13	0.38	1.09	0.67	1.51	0.34	2.54
f_n = 0.062 mm/rev								
	ap = 0.4 mm				ap = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	293	216	66	509	440	437	39	526
Minimum	250	185	33	468	412	405	22	502
Maximum	457	226	74	546	455	480	43	551
Stand. dev.	12.8	5.0	4.7	10.1	6.8	10.8	3.1	8.3
Stand. error	0.73	0.29	0.27	0.58	0.40	0.63	0.18	0.49
	ap = 1.2 mm				*ap* = 1.6 mm			
Mean	500	489	46	511	615	488	1	509
Minimum	459	435	43	483	577	452	-1	488
Maximum	517	535	48	550	629	508	9	549
Stand. dev.	6.4	16.3	0.9	9.4	6.1	8.4	1.4	7.4
Stand. error	0.37	0.95	0.05	0.55	0.37	0.51	0.08	0.45
f_n = 0.083 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	272	262	105	502	433	703	13	544
Minimum	251	199	75	418	402	635	6	430
Maximum	298	285	128	597	458	732	22	622
Stand. dev.	7.0	12.7	10.7	18.7	11.8	13.0	3.6	28.6
Stand. error	0.35	0.64	0.54	0.95	0.60	0.66	0.18	1.46
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	500	767	-4	526	589	625	24	530
Minimum	489	627	-23	467	540	480	4	395
Maximum	514	910	14	558	621	847	37	603
Stand. dev.	3.6	46.6	6.2	10.4	7.6	57.0	7.6	21.9
Stand. error	0.18	2.37	0.32	0.53	0.39	2.92	0.39	1.13

For each value of the depth of cut, as the feed increases, the value of the F_c force increases too. The highest mean value of force F_f (782 N) was obtained for a cutting depth equal 1.6 mm and feed 0.044 mm/rev. The obtained results show, that for the analyzed feed values, along with the increase depth of cut, the average force value F_f increases too. For cutting speed of 152 m/min, the largest force value F_p = 105 N was obtained for a_p = 0.4 mm and f = 0.083 mm/rev. However, as the values of these increase parameters, the F_p forces decrease.

Tab. 4. The results of statistic analysis of cutting forces and temperature for V_c = 219 m/min

V_c = 219 m/min								
f_n = 0.044 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	73	19	20	388	122	32	20	380
Minimum	67	13	18	354	110	19	2	331
Maximum	78	21	24	397	139	50	25	413
Stand. dev.	1.7	1.4	1.2	3.9	5.0	6.5	6.1	14.6
Stand. error	0.09	0.07	0.06	0.20	0.25	0.33	0.31	0.74
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	172	41	6	373	226	73	16	377
Minimum	165	37	-4	348	216	65	7	357
Maximum	190	69	26	402	248	104	28	404
Stand. dev.	3.3	4.8	6.6	6.1	4.2	4.5	1.9	5.6
Stand. error	0.17	0.24	0.34	0.31	0.21	0.23	0.10	0.28
fn = 0.062 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	103	28	23	386	100	26	24	389
Minimum	95	22	20	345	91	21	22	352
Maximum	115	40	28	443	111	36	27	438
Stand. dev.	5.1	4.3	1.8	15.4	4.6	3.7	1.1	15.8
Stand. error	0.31	0.26	0.11	0.94	0.28	0.23	0.07	0.97
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	222	39	1	374	293	77	24	369
Minimum	206	36	-6	351	233	51	-15	348
Maximum	229	45	5	395	309	90	29	398
Stand. dev.	3.4	1.6	1.5	6.0	6.5	5.4	3.2	9.0
Stand. error	0.20	0.10	0.09	0.36	0.39	0.32	0.19	0.54
fn = 0.083 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	128	60	35	439	206	90	34	450
Minimum	119	49	31	388	196	78	10	382
Maximum	145	70	38	488	242	131	38	572
Stand. dev.	4.1	4.5	1.5	18.7	5.6	5.3	3.3	47.5
Stand. error	0.29	0.31	0.11	1.30	0.39	0.37	0.23	3.31
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	285	83	9	417	378	124	35	398
Minimum	264	77	-4	343	351	82	-8	345
Maximum	297	91	16	450	403	152	51	439
Stand. dev.	4.8	2.4	4.8	16.7	8.3	16.1	13.3	18.9
Stand. error	0.33	0.17	0.33	1.17	0.58	1.12	0.92	1.31

Table 4 shows the results of the basic statistical analysis of the measurement of F_c, F_f, F_p forces, and temperature for cutting speed equal 219 m/min. For each value of the depth of cut, as the feed increases, the value of the F_c force increases. The highest mean value of force F_c (378 N) was obtained for a depth of cut equal 1.6 mm and feed 0.083 mm/rev.

The highest mean values of the feed force occur for the highest feed value f = 0.083 mm/rev for the all range of the analysed depth of cut. The maximum mean values of force Fp do not achieve the value 40 N. Increasing the cutting speed by 67 m/min resulted in a reduction in the value of all analysed cutting forces. The value of temperature on the rake surface during the turning process was over 500ºC for V_c = 153 m/min, and the increase of V_c to 219 m/min enabled to obtain average temperatures lower than 100ºC

Table 5 shows the results of the basic statistical analysis of the measurement of F_c, F_f, F_p forces, and temperature for cutting speed equal 304 m/min.

The highest mean value of force F_c (481 N) was obtained for a cutting depth equal 1.6 mm and feed 0.062 mm/rev. For each value of the depth of cut, as the feed increases, the value of the F_c force increases to. The highest mean value of force F_f (402 N) was obtained for the same cutting parameters. This value differs significantly from the rest of the force F_f. This is due to the formation of unfavourable, snarled chips, which disturbed the cutting process.

Figure 3 shows the effect of depth of cut on the change in the value of cutting force (F_c), feed force (F_f), radial force (F_p) and temperature (T) during turning process for V_c = 304 m/min, f = 0.063 mm/rev and a_p = 1.6 mm.

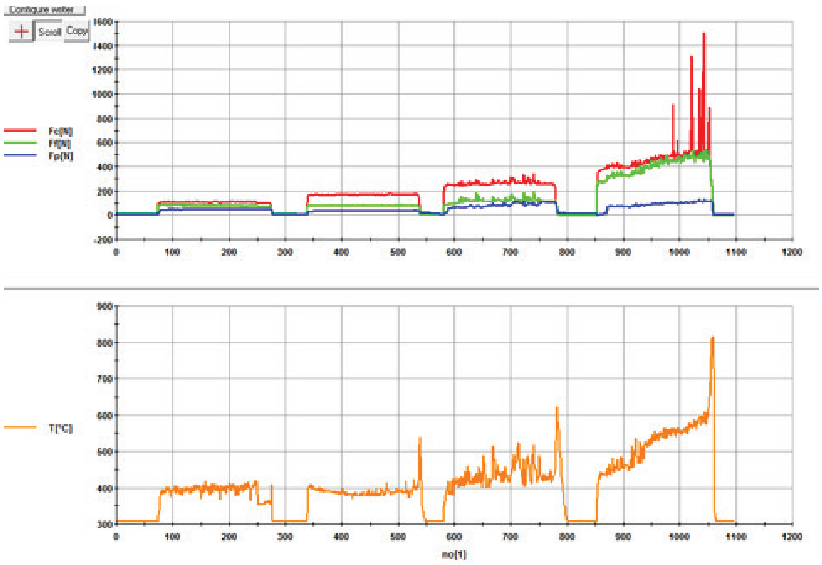

Fig. 2. Effect of change of cutting depth on value of cutting forces and temperature

Figures 3-6 show a graphic interpretation of the influence of the change in cutting parameters on the analysed forces and cutting temperature.

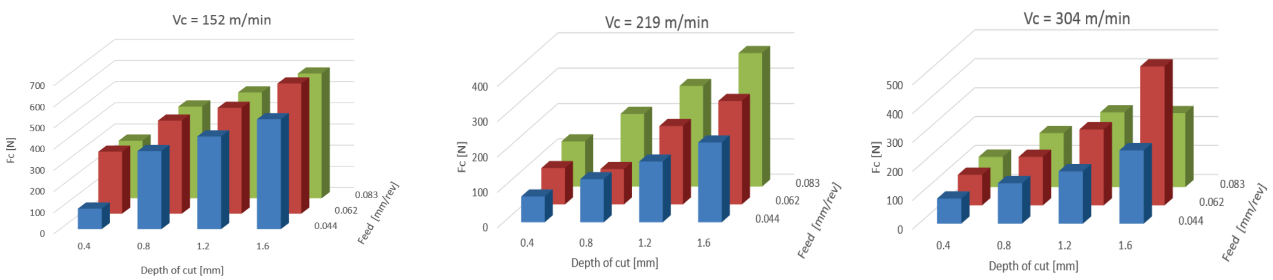

Fig. 3. The influence of changing of cutting parameters on F_c for V_c = 152, 219, 304 m/min

Tab. 5. The results of statistic analysis of cutting forces and temperature for V_c = 304 m/min

V_c = 304 m/min								
f_n = 0.044 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	87	84	22	382	140	92	19	393
Minimum	60	73	3	310	129	86	2	350
Maximum	91	89	25	395	152	103	21	407
Stand. dev.	2.6	2.4	2.1	9.6	3.0	3.3	2.7	6.4
Stand. error	0.16	0.15	0.12	0.57	0.18	0.19	0.16	0.38
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	181	98	6	383	254	172	2	391
Minimum	164	94	1	361	231	150	-18	346
Maximum	206	130	17	415	316	238	34	564
Stand. dev.	3.8	3.5	3.2	6.6	12.4	21.5	18.3	27.3
Stand. error	0.23	0.21	0.19	0.40	0.74	1.28	1.09	1.62
f_n = 0.062 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	106	77	45	391	168	77	30	388
Minimum	95	67	36	352	160	74	21	371
Maximum	113	86	48	420	175	80	35	422
Stand. dev.	3.4	4.1	2.0	16.0	2.7	1.2	1.8	8.5
Stand. error	0.25	0.29	0.14	1.15	0.19	0.08	0.13	0.61
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	263	119	80	432	481	402	83	519
Minimum	236	81	16	360	352	265	-2	411
Maximum	341	200	113	524	1509	547	130	691
Stand. dev.	16.2	18.9	19.8	28.6	144.2	72.9	27.7	55.3
Stand. error	1.16	1.35	1.42	2.05	10.17	4.34	1.65	3.29
f_n = 0.083 mm/rev								
	a_p = 0.4 mm				a_p = 0.8 mm			
	F_c [N]	F_f [N]	F_p [N]	T [ºC]	F_c [N]	F_f [N]	F_p [N]	T [ºC]
Mean	105	15	29	434	187	33	27	488
Minimum	100	13	27	409	177	12	15	393
Maximum	111	19	31	459	205	44	35	556
Stand. dev.	2.5	1.0	1.0	10.3	4.5	4.3	2.8	26.4
Stand. error	0.23	0.09	0.09	0.94	0.37	0.35	0.23	2.17
	a_p = 1.2 mm				a_p = 1.6 mm			
Mean	259	17	7	369	356	55	37	379
Minimum	247	15	-2	341	338	26	-9	345
Maximum	270	21	15	387	373	73	51	408
Stand. dev.	5.0	1.2	3.7	9.6	6.1	11.2	7.6	7.7
Stand. error	0.41	0.10	0.30	0.79	0.50	0.91	0.62	0.63

Figure 7 shows a view of cutting insert during and after the turning process. The nose radius has been damaged on the flank and rake surfaces are clearly visible wear surface defects. Such damage of the nose of the insert radius could have impact on the significant changes in the analysed forces as well as on the temperatures during the cutting process. During the test, wear of the nose radius of the cutting insert was not observed.

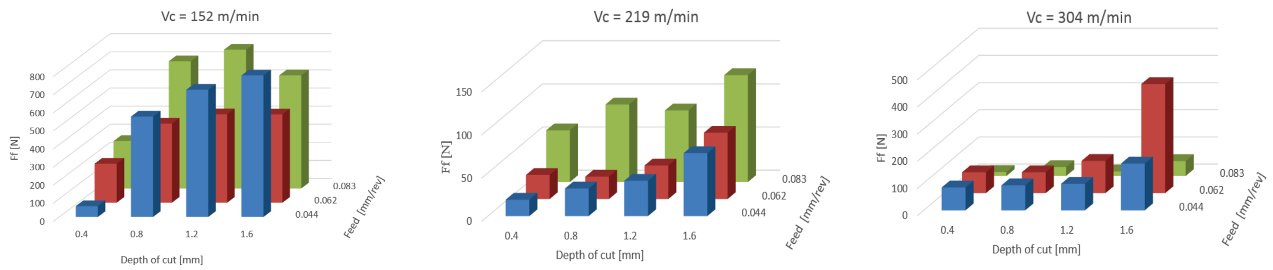

Fig. 4. The influence of changing of cutting parameters on F_f for V_c = 152, 219, 304 m/min

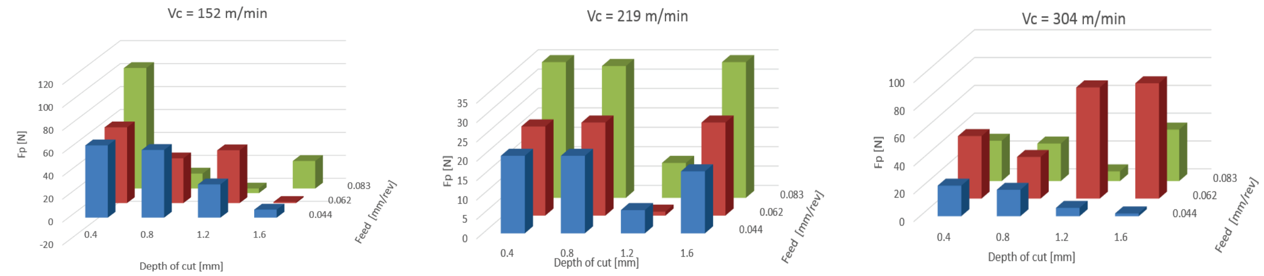

Fig. 5. The influence of changing of cutting parameters on F_p for V_c = 152, 219, 304 m/min

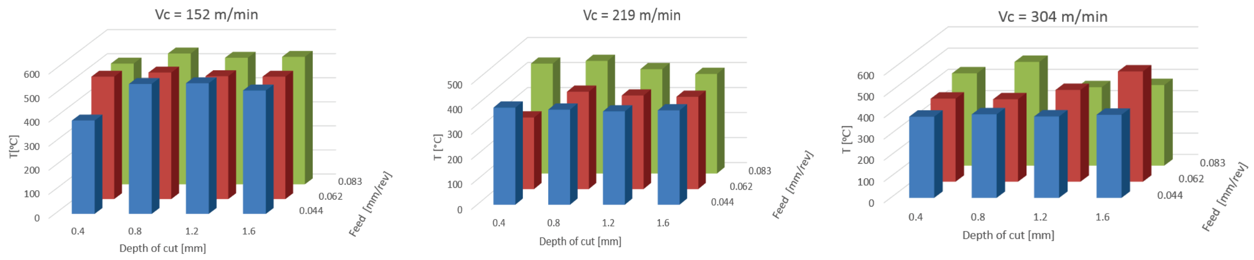

Fig. 6. The influence of changing of cutting parameters on T for V_c = 152, 219, 304 m/min

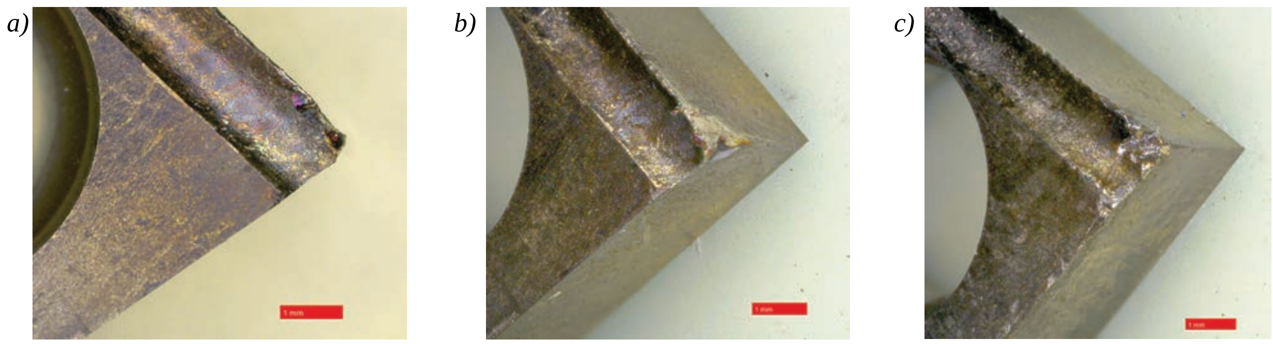

Fig. 7. View of insert: a, b) during turning process, c) after turning process

4. Conclusions

This article is one of a series on determining the set of input, constant, and disturbing factors for the turning process of shaft pins made of a stainless steel. Analysis of the results showed significant differences in the values obtained for the cutting forces and temperature during changing of cutting parameters.

The turning process was carried out CCET09T302R-MF insert with the depth of cut a_p = 0.4-1.6 mm and feed 0.044 to 0.083 mm/rev, makes it possible to find the most favourable range of the inserts work in terms of obtained forces. The research showed that for the turning process carried out on a conventional CDS 6250 BX-1000 lathe the most favourable treatment conditions occurred for the cutting speed value equal 219 m/min. Conventional lathes are often equipped only with multistage rotational speed control. This causes the problem of ensuring optimal values of the cutting speed for individual types of cutting inserts. In addition, the appropriate selection of cutting parameters has a significant impact on the chip forming process. In research, during incorrect selection of feed and depth of cut for the analysed V_c values, unfavourable snarled and continuous chips were formed. For a correct cutting process, it is important, that short chips should be formed during the machining process.

An important role in the process of shaping the surface layer is production efficiency while ensuring the appropriate geometric structure of surface. Therefore, simultaneously the research is conducted to determine the effect of changing treatment conditions on the surface roughness parameters. In the next research, a multiple regression analysis will be performed to determine the equations for individual forces for variable treatment conditions.

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