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Analysis of Product Quality Through Mechanical Properties and Determining Optimal Process Parameters of Untreated and Heat-Treated AISI 1050 Alloy during Turning Operation

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Abstract. AISI 1050 alloy has a wide range of applications and were subjected to machining operations. The purpose of the study is to find the optimum input plain turning process parameters at three levels, using L18 orthogonal array and grey relation analysis; and to investigate the mechanical and microscopic properties of the AISI 1050 alloy before (untreated, UT) and after annealing (AN) (heat-treatment, HT) process. The results of conducted experiments revealed the optimum process parameters as following for the untreated specimens: spindle speed at 3500 r.p.m., feed 0.08 mm/rev, depth of cut at 0.6 mm, insert corner radius at 4mm, and cutting fluid concentration at 12 %, are the most optimum conditions to obtain minimum power consumption for the untreated specimens. Whereas, a spindle speed at 3500 r.p.m., feed at 0.08 mm/rev, depth of cut at 0.6mm, insert corner radius at 4 mm, and cutting fluid concentration at 12 % are the optimum parameter values for the treated specimens.

Introduction

The AISI 1050 alloy steel is widely used for the manufacturing of the turbine blades, brackets, brake discs, clips, clutches, springs, washers and gears and for a wide range of applications that can be used for various purposes for its mechanical properties [1-5]. Most of the components used for the above applications were invariably machined and component like shafts were turned using conventional or CNC lathes. Hence, it becomes important to study about the cutting parameters involved in a turning operation and hence the present study was made [4-17].

Materials and Methods

AISI 1050 steel was obtained in rod form from Ms. Vaishnavi Metals, India, and samples were cut for 50 mm diameter and 40 mm in length. Some specimens were annealed in muffle furnace at a temperature of 925 °C and for a soaking period of 120 minutes. The annealed specimens were cooled to room temperature in normal atmospheric conditions. A comparison of the un-treated and heat-heated (annealed) specimens of AISI 1050 were investigated for its grain size, mechanical properties like yield strength, ultimate tensile strength, and percentage elongation. BHN for the above two conditions and for the five input machining parameters in a CNC lathe namely: spindle speed, feed, depth of cut, nose radius, cutting fluid concentration (Water soluble cutting fluid of Atlantic lubrication), all at three levels as given in Table 1. Four responses of the machined surfaces were investigated namely: surface roughness (Ra) (Talysurf), roundness (S) (Machine Vision), Material

Removal Rate (MRR) (volume loss) and Power Consumption (PC) (L&T energy meter). Carbide cutting tool was used for the process of plain turning. The process parameters were then optimized for L18 orthogonal array using Grey relational analysis and ANOVA.

Table 1: Plain turning process parameter design

Parameters	Notation	Levels		
		1	2	3
Spindle Speed [r.p.m]	A	3000	3500	4000
Feed [mm/rev.]	B	0.08	0.1	0.12
Depth of Cut [mm]	C	0.4	0.6	0.8
Insert Corner Radius [mm]	D	4	5	6
Cutting fluid concentration [%]	E	4%	8%	12%

Results and Discussions

Effect of heat treatment on mechanical properties

The effect of heat-treatment (annealing) on the microstructure (grain size) and mechanical properties like BHN, Tensile Strength, Yield Strength, and percentage of Elongation were measured and compared with that of the untreated samples is shown in Table 2.

Table 2: Mechanical Properties of Untreated and Annealing

Condition	Grain Size (ASTM)	Hardness (HBW)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (% 50mm GL)
Un Treated	7.0	269	786	646	17.32%
Annealing	8.5	201	708	491	23.00%

There was an increase in the observed grain size in the annealed samples, whose ASTM grain size number was measured to be 8.5, when compared with the untreated samples which had a grain size number of 7. The grain size growth might be attributed to the alignment of atoms at the grain boundaries due to acquired thermal energy supplied during the annealing process.

There was an observed decrease in the Brinell harness (HBW) to a value 201 HBW for the annealed samples from 269 HBW for the untreated ones. The decrease in the Brinell hardness is attributed to the increase in the grain size and decrease in the strength due to reduction in grain boundary strengthening.

When comparing the mechanical tensile properties, the annealed samples indicated a reduction in the values of tensile and yield strength and with an increase in the percentage of elongation when compared with the un-treated specimens. The changes in the tensile properties were also attributed to the change in the grain boundary strengthening phenomenon that depends upon the grain size.

Experimentation

Experiments were designed according to L18 orthogonal array with five input parameters or factors of Machining (turning) each of at three levels; for both Untreated and Annealed AISI 1050 specimens as presented in Table 3. The output parameters investigated being Surface roughness (Ra), Roundness (S), Maximum Material Removal Rate (MRR), and Power Consumption (PC), whose grey relation grades are shown in Table 4.

Table 3: Experimental Orthogonal Array Responses

Exp	Input Parameters					Ra [µm]		S [µm]		MRR [$10^3 mm^3/min$]		PC[Watt]	
	A	B	C	D	E	UT	AN	UT	AN	UT	AN	UT	AN
1	3000	0.08	0.4	4	4	0.992	0.934	1.432	1.232	8.478	8.478	0.515	0.495
2	3000	0.08	0.4	4	8	1.221	1.005	1.389	1.352	8.289	8.289	0.504	0.474
3	3000	0.08	0.4	4	12	0.984	0.843	1.234	1.126	8.101	8.101	0.492	0.467
4	3000	0.1	0.6	5	4	1.214	1.023	1.289	1.204	19.782	19.782	1.202	0.908
5	3000	0.1	0.6	5	8	0.984	0.882	1.321	1.266	19.311	19.311	1.174	0.909
6	3000	0.1	0.6	5	12	0.996	0.926	1.312	1.213	18.84	18.84	1.145	0.989
7	3500	0.12	0.8	6	4	0.986	0.907	1.123	1.321	38.574	38.574	2.345	1.456
8	3500	0.12	0.8	6	8	0.978	0.895	1.323	1.256	37.585	37.585	2.285	1.679
9	3500	0.12	0.8	6	12	0.996	0.921	1.312	1.285	36.596	36.596	2.225	1.897
10	3500	0.08	0.4	4	4	0.956	0.882	1.398	1.301	7.912	7.912	0.481	0.234
11	3500	0.08	0.4	4	8	0.945	0.913	1.398	1.285	7.693	7.693	0.468	0.346
12	3500	0.08	0.4	4	12	0.912	0.854	1.398	1.215	7.473	7.473	0.454	0.345
13	4000	0.1	0.6	5	4	0.989	0.966	1.309	1.206	20.72	20.72	1.260	0.987
14	4000	0.1	0.6	5	8	0.976	0.893	1.312	1.301	20.096	20.096	1.222	0.983
15	4000	0.1	0.6	5	12	0.967	0.882	1.312	1.285	19.468	19.468	1.183	1.076
16	4000	0.12	0.8	6	4	0.956	0.902	1.315	1.209	33.912	33.912	2.061	1.354
17	4000	0.12	0.8	6	8	1.123	0.915	1.345	1.231	32.782	32.782	1.993	1.643
18	4000	0.12	0.8	6	12	1.045	0.934	1.367	1.232	31.652	31.652	1.924	1.431

The results of the ANOVA revealed that the spindle speed was found to be the most significant factor affecting the surface roughness and contributes to nearly 27 % or more in the cases of untreated and annealed samples, whereas, Feed, Depth of cut, Insert Corner Radius, and Cutting fluid concentration contribute distributed equal for all the samples.

Analysis results also revealed that the Feed rate was found to be the most significant factors affecting the roundness of untreated samples, followed by Spindle Speed. Depth of cut, Insert Corner Radius and Cutting Fluid concentration contribute equally for the Untreated specimens; and spindle speed was found to be the most significant factors affecting the roundness in case of annealed specimens. Feed, Depth of cut, Insert Corner Radius and Cutting Fluid concentration contribute equally for the Treated specimen.

Spindle Speed was found to be the most significant factors affecting the MRR, whereas, Feed, Depth of cut, Insert Corner Radius and Cutting Fluid concentration contribute in a decreasing order respectively for both the Untreated and Treated specimen. Spindle Speed is found to be the most significant factors affecting the power consumption for both annealed and untreated samples, and Feed, Depth of cut, Insert Corner Radius and Cutting Fluid concentration contribute in a decreasing order respectively with Depth of cut and Insert Corner Radius having equal contribution for the Untreated specimen.

Table 4: Grey relational co-efficient and grey grade values

Trail No	Normalized value Untreated and Annealed								Grey relation co efficient Untreated and Annealed								Grey relation For			
	Ra [µm]		S [µm]		MRR [$10^3 mm^3/min$]		PC[Watt]		Ra [µm]		S [µm]		MRR [$10^3 mm^3/min$]		PC[Watt]		Grade		Rank	
	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN	UT	AN
1	0.29	0.53	1.00	0.49	0.08	0.08	0.08	0.36	0.41	0.52	1.00	0.50	0.35	0.35	0.35	0.44	0.53	0.45	12	16
2	1.00	0.91	0.87	1.00	0.06	0.06	0.06	0.34	1.00	0.84	0.80	1.00	0.35	0.35	0.35	0.43	0.62	0.66	8	5
3	0.26	0.00	0.39	0.00	0.05	0.05	0.05	0.33	0.40	0.33	0.45	0.33	0.34	0.34	0.34	0.43	0.39	0.36	18	18
4	0.98	1.00	0.57	0.37	0.59	0.59	0.59	0.65	0.96	1.00	0.54	0.44	0.55	0.55	0.55	0.59	0.65	0.64	6	8
5	0.26	0.23	0.67	0.64	0.58	0.58	0.58	0.65	0.40	0.39	0.60	0.58	0.54	0.54	0.54	0.59	0.52	0.53	13	12
6	0.30	0.48	0.64	0.41	0.56	0.56	0.56	0.69	0.42	0.49	0.58	0.46	0.53	0.53	0.53	0.62	0.52	0.53	14	13
7	0.27	0.38	0.00	0.87	1.00	1.00	1.00	0.87	0.41	0.45	0.33	0.80	1.00	1.00	1.00	0.80	0.68	0.76	4	2
8	0.24	0.31	0.67	0.60	0.98	0.98	0.98	0.94	0.40	0.42	0.61	0.55	0.97	0.97	0.97	0.90	0.74	0.71	1	3
9	0.20	0.16	0.04	0.84	1.00	1.00	1.00	1.00	0.38	0.37	0.34	0.75	1.00	1.00	1.00	1.00	0.68	0.78	5	1
10	0.10	0.07	1.00	1.00	0.04	0.04	0.67	0.53	0.36	0.35	1.00	1.00	0.35	0.35	0.60	0.52	0.58	0.55	9	11
11	0.08	0.15	1.00	0.84	0.02	0.02	0.59	0.53	0.35	0.37	1.00	0.75	0.34	0.34	0.55	0.52	0.56	0.49	10	15
12	0.00	0.00	1.00	0.10	0.00	0.00	0.58	0.53	0.33	0.33	1.00	0.36	0.33	0.33	0.54	0.52	0.55	0.38	11	17
13	0.18	0.27	0.00	0.00	0.64	0.64	0.85	0.82	0.38	0.41	0.33	0.33	0.58	0.58	0.77	0.74	0.52	0.51	15	14
14	0.15	0.10	0.04	1.00	0.62	0.62	0.84	0.82	0.37	0.36	0.34	1.00	0.57	0.57	0.76	0.73	0.51	0.67	16	4
15	0.13	0.07	0.04	0.84	0.60	0.60	0.83	0.84	0.36	0.35	0.34	0.75	0.56	0.56	0.75	0.76	0.50	0.61	17	10
16	0.10	0.12	0.07	0.03	0.95	0.95	0.98	0.91	0.36	0.36	0.35	0.34	0.91	0.91	0.96	0.84	0.65	0.61	7	9
17	0.46	0.15	0.41	0.27	0.93	0.93	0.97	0.96	0.48	0.37	0.46	0.41	0.88	0.88	0.95	0.93	0.69	0.65	3	7
18	0.47	0.53	0.81	0.49	0.88	0.88	0.88	0.87	0.48	0.52	0.72	0.50	0.81	0.81	0.81	0.79	0.70	0.65	2	6

Confirmation Test:

The confirmation experiment was conducted at the optimum settings found through grey relation analysis to verify the quality characteristics for AISI 1050 by turning process as per the investigation. The response values of the confirmation experiment trial at the optimal settings are Spindle Speed at 3500 r.p.m., Feed 0.08mm/rev, Depth of Cut at 0.6mm, Insert Corner Radius at 4mm, and Cutting Fluid Concentration at 12%, are the most optimum conditions to obtain minimum Power consumption for the Untreated specimens. Whereas, a spindle Speed at 3500 r.p.m., Feed at 0.08mm/rev, Depth of Cut at 0.6mm, Insert Corner Radius at 4mm, and Cutting Fluid Concentration at 12% are the optimum parameter values for the Treated specimens. The experimental values at the optimum settings confirmed the predicted values.

Conclusions

The following points can be concluded based on experimentation and analysis using ANOVA and Grey relations analysis which are as follows:

There was an observed increase in the grain size of the annealed samples of AISI 1050 specimens which were attributed to the thermal effect at grain boundaries. The reduction in the yield and ultimate tensile strengths, and increase in the percentage elongation of the annealed specimens were also attributed to the increase in the grain size and reduction in the grain boundary, which reduces the strength of the material. Optimum cutting parameters for both the untreated and heat-treated (annealed) specimens were found for the L18 orthogonal array configurations using Grey Relations algorithm and were verified experimentally. The optimum process parameters were found to be a Spindle Speed at 3500 r.p.m., Feed 0.08mm/rev, Depth of Cut at 0.6mm, Insert Corner Radius at 4mm, and Cutting Fluid Concentration at 12%, are the most optimum conditions to obtain minimum Power consumption for the Untreated specimens. Whereas, a spindle Speed at 3500 r.p.m., Feed at 0.08mm/rev, Depth of Cut at 0.6mm, Insert Corner Radius at 4mm, and Cutting Fluid Concentration at 12% are the optimum parameter values for the Treated specimens.

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