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Research paper



Optimization of Laser Cutting Parameters on 700MC Steel Using Grey Relational Analysis

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Abstract

This paper presents an investigation of the optimization of laser cutting parameters on 700MC steel. The cutting parameters investigated in this study are focused on Laser power, cutting speed, and gas pressure. Full factorial design (3k) is employed as the random run of the experimental. Grey relational analysis is used to determine the optimization of these parameters. The experimental results show that the optimal cutting condition for laser power, cutting speed and gas pressure is 2600W, 1500 mm/min and 0.06 bars, respectively. In addition, the experimental validation provided the surface roughness and kerf width is 3.870 µm and 0.696 mm respectively.

Keywords: *grey relational analysis; laser cutting; optimization parameter*

1. Introduction

Laser light or light amplification by stimulation emission of radiation is one of the thermal energy machining processes. Hence, Laser beam machining (LBM) is a process to cut materials. A high-energy laser beam is focused on a minimal region. The focused beam causes melting, vaporization or chemical degradation throughout the depth of material. The melted and transformed materials are removed with high pressure assist gas. LBM is widely used for complex parts in the manufacturing industries such as aerospace, electronics, civil structures, and automobiles because of a low cost, high precision, and productivity [1-2]. However, the several factors of LBM process that affect the quality characteristics (i.e. LBM variables, material property, and operating) [3]. Effect of key process parameters, such as laser power, cutting speed, and gas pressure, on surface roughness and kerf width have been studied [4-6].

It well know that various methods using to predict the optimization parameters (i.e. mathematical and statistical, or collection of both mathematical and statistical technique). The response surface methodology (RSM) is employed to establish the reliable mathematical relationships between the parameters and desired responses [7]. A full factorial design of experiment (DOE) is used to collect the necessary data for developing and validating the models [8], but that method has a large number of experiments. Taguchi experimental design method is applied to significantly reduce the number of experiments [9] but simultaneous optimization of these machining characteristics has not been reported in the full factorial design and Taguchi. Generally, Grey relational analysis base on Taguchi experimental design method is used for the optimization of multifactor experiments. Grey relational analysis is one of the efficient solutions to the uncertainty, multi-input and discrete data problems [10]. This method defined the optimization process as a decision making process in which decision goals are represented a maximum of the average grey relational grade. Grey relational analysis was applied to optimize the input parameters simultaneously considering multiple output variables [11].

The main purpose of this paper is to investigate optimization parameters of laser cutting on 700 MC steel. The investigate laser cutting parameters were laser power, cutting speed, and gas pressure. Grey relational analysis method to predict both the surface roughness and kerf response of laser cutting.

2. Materials and Procedures

The 700MC steel is a high yield structural steel supplied under the EN10149: Part2 specification. Due to the materials high yield (700Mpa min.) it can be used in a variety of load bearing applications. The steel as above which has 20x30x6 mm rectangular bar was used in this study. For the procedure, the experiments were carried out on the AMADA laser cutting machine model FO3015 for cutting workpieces. The full factorial design (3^k) was generated the experiments. The symbol k is a number of regulated parameters. This study carried out with three experimental parameters of laser cutting and three replicate levels of each factor conditions that showed in Table 1. Hence, eighty-one experiments were carried out.

In this study, the surface roughness and kerf response of laser cutting is investigated. For surface roughness testing, the Mahr surface roughness machine model MarSurf PSI was used. Also the kerf measuring, the JENCO optical microscope model V203410 was used throughout Edn-2 software. Finally, the optimal cutting parameters were evaluated by grey relational analysis.

Table 1: The Experimental Parameters and Levels on the Laser Process Cutting

Parameters	Units	Levels		
		Level 1	Level 2	Level 3
Laser power	watts	2600	2800	3000
Cutting speed	mm/min	1000	1500	2000
Gas pressure	bar	0.04	0.06	0.08

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3. Results and discussion

Figure 1 and Figure 2 demonstrate laser cutting process and specimen workpiece, respectively. The details of experiments and normalization values are shown in Appendix A.



Fig. 1: Laser cutting process.



Fig. 2: The specimen workpiece throughout cutting process.

Grey relation analysis is used to optimize the turning operation with multiple performance characteristics. For the method, all initial experimental data were normalized in range between zero and one by (1) or (2). Equation (1) is used for responses that larger-better value. Other hand, (2) is used for responses that smaller-better value.

$$x_i^*(k)=\frac{x_i^{(0)}(k) - \min_{all(i)} x_i^{(0)}(k)}{\max_{all(i)} x_i^{(0)}(k) - \min_{all(i)} x_i^{(0)}(k)} \quad (1)$$

$$x_i^*(k)=\frac{\max_{all(i)} x_i^{(0)}(k) - x_i^{(0)}(k)}{\max_{all(i)} x_i^{(0)}(k) - \min_{all(i)} x_i^{(0)}(k)} \quad (2)$$

where $x_i^*(k)$ is the value of response i^{th} of scenario k, $x_i^{(0)}(k)$ is initial value of response i^{th} of scenario k, $\min_{all(i)} x_i^{(0)}(k)$ is the minimum initial value of scenario k and $\max_{all(i)} x_i^{(0)}(k)$ is the maximum initial value of scenario k.

In this study, the response of surface roughness and kerf of laser cutting was the smaller-better response characteristic. Therefore, the normalized equation as (2) was used. The maximum and minimum experimental result was 0 and 1, respectively. The grey relational coefficient is calculated by (3). In this experiment, the distinguishing coefficient was set as 0.5 initially [12] that infer to coordinate the surface roughness and kerf of laser cutting.

$$\zeta_i(k)=\frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}} \quad (3)$$

Where $\zeta_i(k)$ is grey relational coefficient of response i^{th} of scenario k and ζ is distinguishing coefficient, $\zeta \in [0,1]$. Δ_{min}, Δ_{max} and $\Delta_{0i}(k)$ can be calculated by (4), (5) and (6), respectively.

$$\Delta_{min}=\min_{\forall j\in i}\min_{\forall k}\left|x_0^*(k)-x_j^*(k)\right| \quad (4)$$

$$\Delta_{max}=\max_{\forall j\in i}\max_{\forall k}\left|x_0^*(k)-x_j^*(k)\right| \quad (5)$$

$$\Delta_{0i}(k)=\left|x_0^*(k)-x_i^*(k)\right| \quad (6)$$

Where $\Delta_{0i}(k)$ is different between ideal response $x_0^*(k)$ and experimental response $x_i^*(k)$.

The grey relational grade is calculated after grey relational coefficients completely carried out. This value can be calculated as (7).

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\zeta_i(k) \quad (7)$$

Where γ_i is grey relational grade of response i^{th}. The results of grey relational coefficient and grey relational grade demonstrate in table 2.

Table 2: The Experimental Parameters and Levels on the Laser Process Cutting

Run	Grey Relational Coefficient		Grey Relational Grade
	Surface Roughness	Kerf	
1	0.3333	0.4286	0.3810
2	0.3782	0.4925	0.4354
3	0.8158	0.3626	0.5892
4	0.7028	0.5410	0.6219
5	0.3362	0.3882	0.3622
6	0.3443	0.4521	0.3982
7	0.6246	0.4783	0.5514
8	0.4282	0.4648	0.4465
9	0.5168	1.0000	0.7584
10	0.6347	0.4400	0.5374
11	0.4236	0.4783	0.4509
12	0.5344	0.4521	0.4932
13	0.4776	0.5077	0.4926
14	0.3890	0.4400	0.4145
15	0.6066	0.5077	0.5571
16	0.4857	0.4074	0.4466
17	0.7872	0.3708	0.5790
18	0.3642	0.4648	0.4145
19	0.3369	0.3474	0.3421
20	0.4353	0.4521	0.4437
21	0.9236	0.6226	0.7731
22	0.5044	0.4177	0.4611
23	0.5344	0.4648	0.4996
24	0.4754	0.3793	0.4274
25	0.5601	0.4074	0.4838
26	0.3984	0.5077	0.4530
27	0.4224	0.4074	0.4149
28	0.5744	0.4521	0.5132
29	0.8179	0.3708	0.5944
30	0.5446	0.4074	0.4760
31	0.5973	0.5593	0.5783
32	0.7156	0.5593	0.6375
33	0.3398	0.4521	0.3959
34	0.3316	0.4400	0.3858
Run	Grey Relational Coefficient		Grey Relational Grade
	Surface Roughness	Kerf	
35	0.5020	0.4521	0.4770
36	0.7322	0.3548	0.5435
37	0.6981	0.3793	0.5387
38	0.4575	0.5410	0.4992
39	0.5808	0.4925	0.5367
40	0.6874	0.3474	0.5174

41	0.4957	0.4783	0.4870
42	0.4972	0.4074	0.4523
43	0.6478	0.4925	0.5702
44	0.5797	0.3882	0.4840
45	0.5152	0.4177	0.4664
46	0.5819	0.5238	0.5528
47	0.5611	0.4925	0.5268
48	0.4471	0.5410	0.4940
49	0.7444	0.3333	0.5389
50	0.5985	0.4783	0.5384
50	0.7172	0.3976	0.5574
52	0.5185	0.5077	0.5131
53	0.5126	0.4648	0.4887
54	0.7172	0.4521	0.5846
55	0.5052	0.3976	0.4514
56	0.6019	0.4400	0.5210
57	0.8116	0.7333	0.7725
58	0.7091	0.5593	0.6342
59	0.9236	0.5593	0.7415
60	0.8201	0.4648	0.6424
61	0.7853	0.5789	0.6821
62	0.7643	0.5593	0.6618
63	0.7289	0.6735	0.7012
64	0.7587	0.5410	0.6499
65	0.7322	0.5593	0.6458
66	0.7972	0.5238	0.6605
67	0.7853	0.4783	0.6318
68	0.8605	0.5789	0.7197
69	0.8897	0.5789	0.7343
70	0.7189	0.6226	0.6707
71	0.8535	0.5789	0.7162
72	0.9076	0.7333	0.8205
73	0.9182	0.6226	0.7704
74	0.9264	0.6226	0.7745
75	1.0000	0.5593	0.7797
76	0.7624	0.5593	0.6609
77	0.9516	0.3976	0.6746
78	0.8581	0.5789	0.7185
79	0.9319	0.5410	0.7364
80	0.9813	0.5789	0.7801
81	0.9692	0.7333	0.8513

To optimize the laser cutting parameters by using grey relational analysis, the average grey relational grade of each level is investigated. For the method, the maximum average grey relational grade of each parameter was selected. Therefore, the optimal cutting parameters in this experiment are shown in Table 3. Consequently, the optimal parameters of laser cutting in this study were 2600W of laser power, 1500 mm/min cutting speed and 0.06 bar of gas pressure. The experimental validation provided the surface roughness was 3.870 μm and the kerf of laser cutting was 0.696 mm.

Table 3: Average Grey Relational Grade

Parameters	Units	Levels		
		Level 1	Level 2	Level 3
Laser power	watts	0.5894*	0.5494	0.5641
Cutting speed	mm/min	0.5541	0.6043*	0.5445
Gas pressure	bar	0.5514	0.5956*	0.5560
		*Optimal values in this study		

4. Conclusion

The optimization of laser cutting parameters on 700MC steel using grey relational analysis was carried out in this experiment. The response parameters of laser cutting were laser power, cutting speed and gas pressure. As the results, the optimal parameter for each response as above was 2600W, 1500 mm/min and 0.06 bar, respectively. The experimental validation provided the surface roughness and the kerf of laser cutting were 3.870 μm and 0.696 mm, respectively. This study indicated that grey relational analysis approach was effectiveness to optimize a multiple performance characteristics. Furthermore, this approach can be applied to setting other machine functions.

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Appendix A: Experimental Result Data

Run	Laser power (W)	Cutting speed (mm/min)	Gas passer (bar)	Surface roughness (μm)	Kerf (mm)	Surface roughness [0-1]	Kerf [0-1]
1	3,000	1,000	0.04	7.61	0.78	0.0000	0.3333
2	2,800	2,000	0.08	6.49	0.73	0.1781	0.4848
3	3,000	1,000	0.06	2.03	0.85	0.8871	0.1212
4	2,800	1,500	0.04	2.65	0.70	0.7886	0.5758
5	2,800	2,000	0.04	7.53	0.82	0.0127	0.2121
6	2,600	2,000	0.08	7.31	0.76	0.0477	0.3939
7	3,000	1,500	0.08	3.21	0.74	0.6995	0.4545
8	2,800	1,000	0.04	5.52	0.75	0.3323	0.4242
9	2,800	2,000	0.04	4.26	0.56	0.5326	1.000

	0						0
10	2,800	1,000	0.04	3.13	0.77	0.7122	0.3636
11	3,000	1,000	0.08	5.60	0.74	0.3196	0.4545
12	2,800	1,500	0.06	4.06	0.76	0.5644	0.3939
13	2,800	1,000	0.08	4.76	0.72	0.4531	0.5152
14	2,600	2,000	0.08	6.26	0.77	0.2146	0.3636
15	2,600	2,000	0.06	3.36	0.72	0.6757	0.5152
16	2,600	2,000	0.04	4.65	0.80	0.4706	0.2727
Run	La-ser pow-er (W)	Cutting speed (mm/min)	Gas passer (bar)	Surface rough-ness (µm)	Kerf (mm)	Surface rough-ness [0-1]	Kerf [0-1]
17	2,800	2,000	0.08	2.17	0.84	0.8649	0.1515
18	2,800	1,000	0.06	6.81	0.75	0.1272	0.4242
19	3,000	1,500	0.04	7.51	0.87	0.0159	0.0606
20	2,600	2,000	0.04	5.40	0.76	0.3514	0.3939
21	3,000	1,500	0.06	1.58	0.66	0.9587	0.6970
22	3,000	1,500	0.04	4.41	0.79	0.5087	0.3030
23	2,600	1,000	0.06	4.06	0.75	0.5644	0.4242
24	3,000	2,000	0.08	4.79	0.83	0.4483	0.1818
25	2,800	1,000	0.08	3.79	0.80	0.6073	0.2727
26	2,600	1,000	0.08	6.07	0.72	0.2448	0.5152
27	2,800	2,000	0.06	5.62	0.80	0.3164	0.2727
28	2,800	1,000	0.06	3.65	0.76	0.6296	0.3939
29	2,800	1,500	0.04	2.02	0.84	0.8887	0.1515
30	2,600	2,000	0.04	3.95	0.80	0.5819	0.2727
31	2,600	1,500	0.04	3.44	0.69	0.6630	0.6061
32	2,800	1,500	0.04	2.57	0.69	0.8013	0.6061
33	2,600	1,000	0.04	7.43	0.76	0.0286	0.3939
34	3,000	2,000	0.04	7.66	0.77	-0.0079	0.3636
35	3,000	1,500	0.08	4.44	0.76	0.5040	0.3939
36	2,600	1,500	0.08	2.47	0.86	0.8172	0.0909
37	3,000	2,000	0.06	2.68	0.83	0.7838	0.1818
38	3,000	2,000	0.08	5.05	0.70	0.4070	0.5758
39	3,000	1,000	0.06	3.59	0.73	0.6391	0.4848
40	2,800	2,000	0.08	2.75	0.87	0.7727	0.0606
41	2,800	1,000	0.08	4.52	0.74	0.4913	0.4545
42	2,800	1,500	0.08	4.50	0.80	0.4944	0.2727
43	2,600	1,500	0.04	3.03	0.73	0.7281	0.4848
44	2,600	1,000	0.06	3.60	0.82	0.6375	0.2121
45	2,800	2,000	0.06	4.28	0.79	0.5294	0.3030
46	3,000	1,000	0.04	3.58	0.71	0.6407	0.5455
47	3,000	2,000	0.04	3.78	0.73	0.6089	0.4848
48	2,600	2,000	0.06	5.21	0.70	0.3816	0.5758
49	3,000	1,500	0.08	2.40	0.89	0.8283	0.0000
50	2,800	1,500	0.08	3.43	0.74	0.6646	0.4545
51	2,600	1,000	0.06	2.56	0.81	0.8029	0.2424
52	2,800	2,000	0.04	4.24	0.72	0.5358	0.5152
53	3,000	1,000	0.04	4.31	0.75	0.5246	0.4242
54	2,800	1,500	0.06	2.56	0.76	0.8029	0.3939
55	3,000	1,000	0.06	4.40	0.81	0.5103	0.2424
56	3,000	1,500	0.06	3.40	0.77	0.6693	0.3636
57	2,600	1,500	0.04	2.05	0.62	0.8839	0.8182
58	2,600	1,000	0.04	2.61	0.69	0.7949	0.6061
59	2,600	2,000	0.06	1.58	0.69	0.9587	0.6061
60	2,800	1,500	0.08	2.01	0.75	0.8903	0.4242
61	3,000	1,000	0.08	2.18	0.68	0.8633	0.6364
62	2,600	1,500	0.06	2.29	0.69	0.8458	0.6061
63	3,000	1,000	0.08	2.49	0.64	0.8140	0.7576
64	2,600	1,000	0.08	2.32	0.70	0.8410	0.5758
65	2,600	1,500	0.06	2.47	0.69	0.8172	0.6061
66	2,600	1,500	0.08	2.12	0.71	0.8728	0.5455
67	3,000	2,000	0.06	2.18	0.74	0.8633	0.4545
68	2,600	1,500	0.08	1.83	0.68	0.9189	0.6364
69	2,800	2,000	0.06	1.71	0.68	0.9380	0.6364
70	2,600	2,000	0.08	2.55	0.66	0.8045	0.6970
71	2,800	1,000	0.04	1.86	0.68	0.9142	0.6364
72	2,600	1,500	0.06	1.64	0.62	0.9491	0.8182
73	3,000	2,000	0.08	1.60	0.66	0.9555	0.6970
74	2,600	1,000	0.08	1.57	0.66	0.9603	0.6970
75	3,000	1,500	0.06	1.32	0.69	1.0000	0.6061
76	2,800	1,500	0.06	2.30	0.69	0.8442	0.6061
77	3,000	1,500	0.04	1.48	0.81	0.9746	0.2424
78	3,000	2,000	0.04	1.84	0.68	0.9173	0.6364
79	2,800	1,000	0.06	1.55	0.70	0.9634	0.5758
80	3,000	2,000	0.06	1.38	0.68	0.9905	0.6364
81	2,600	1,000	0.04	1.42	0.62	0.9841	0.8182