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Surface Modification of Strenx 900 Steel Using Electrical Discharge Alloying Process with Cu-10Ni- Cr_x Powder Metallurgy Sintered Electrode

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The present investigation aims to coat the layer with Nickel (Ni) and Copper (Cu)over the surface of strenx 900 steel using semi sintered Cu-10Ni-Cr_x electrodes(x = 2, 4 & 6 wt. %). Three different proportions of semi sintered electrodes such as, Cu-10Ni-2 weight percentage of Chromium (Cr), Cu-10Ni-4 wt. % Cr,and Cu-10Ni-6 wt. % Cr were prepared by powder metallurgy route. Electric discharge alloying was completed based on L_9 orthogonal array and alloyed parameters were optimized using Taguchi method. The alloyed surfaces were characterized using scanning electron microscope and atomic force microscopy. The deposition of formation of intermetallic was studied using X- ray diffractometer. Higher Material Transfer Rate (MTR) was obtained at 9A, 350A and 6% chromium using Cu-10 Ni-Cu electrode. The chromium percentage was the foremost factor on Surface Roughness (SR) (73.71%) and MTR(96.56%). From Taguchi approach, the minimum SR was attained at percentage of chromium of 2%, compaction pressure of 250 Megapascal (MPa) and peak current of 9A. The maximum MTR was achieved at 6 percentage of Cr, compaction pressure of 350 MPa and peak current of 3A. Wear loss for Cu-10 Ni-Cr increases linearly with increase in sliding speed from 2m/s to 4m/s respectively.

Keyword: *Electrical discharge alloying, Powder Metallurgy, Taguchi, Characterization, Atomic force microscopy.*

1. Introduction

Electrical discharge machining is an unconventional machining process that involves eroding material from a work piece using a tool called electrode. The process occurs as a sequence of electrical discharges in the presence of dielectric fluid[1]. In case of die sinking Electric Discharge Machining (EDM), the process should be carried out only with the dielectric fluids such as de ionized water; kerosene and EDM oil[2]. EDM process is a suitable technique inmanufacturingof micro holes. It is also an economic, quick and cost effective for producing holes in hard and soft materials[3]. The undesirable layer was formed after machining known as recast layer which is inevitable but could be controlled by varying EDM process parameters. The harder recast layers, on the other hand are helpful in improving the wear resistance, as demonstrated by deliberate surface alloying during EDM. The use of partially sintered Powder Metallurgy (PM) electrodes, EDM in a metal powder suspended dielectric are the most popular methods for performing alloying during EDM that were been widely adopted in the past[4]. The common methods of surface modification using EDM is carried out by two means such as, use of semi sintered electrode and mixing powder in dielectric[5]. The surface texture effects were based on the level of control factors[6]. By using Powder metallurgy tool electrodes, EDM tooling costs can be reduced while tool electrodes can be produced in more quantity[7]

The surface of mould and tools has to be modified in order to increase their service life as well as withstand corrosion. Nevertheless, high machine price and complex processes makes to analyze novel surface modification processes[8]. During EDM of powder metallurgy of Cu-Zn, it was found that more contamination of dielectric medium was obtaineddue to the release of more copper powder from electrode. Poor surface

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topology was obtained due to the frequent occurrences of short circuits and arcs. It was pointed out that machining stability got affected more with increase in copper powder size[9].Powder metallurgy of Cu-Cr electrode yielded low Material Removal Rate (MRR), higher electrode wear ratio and high surface roughness, but electrolytic Cu electrode was better in achieving high MRR than powder metallurgy of Cu-Cr[10]. EDM of Titanium Aluminium Vanadium (Ti–6Al–4V) alloy with powder metallurgy of Cu–Tantalum Carbide (TaC) electrode in urea solution dielectric yielded in the deposition of nitrides, carbides, oxides of titanium and tantalum on the substrate. The base surface hardness improved from 316 Vicker Hardness (HV) to 902 HV[11].During machining carbon steel by suspending tungsten and titanium powders in kerosene dielectric, formation of Titanium Carbide (TiC) and Tungsten Carbide (WC) were identified on substrate due to the reaction between decomposed carbon with titanium and tungsten powders[12].

Very few researchers have carried out investigation on Electric Discharge Alloying (EDA) using Cu-Ni-Cr on strenx 900 steel. This investigation focuses on synthesis ofpowder metallurgy of Cu-10Ni-Cr_x electrodes produced at three different mixing ratios (2, 4, and 6 wt. % Cr), compaction pressure (250, 300, and 350MPa) and peak current (3A, 6A and 9A).

2. Materials and Methods

2.1. Preparation of PM semi sintered Cu-10Ni-Cr_x electrode

The elemental powders of copper, nickel and chromium were mixed in addition of polyvinyl alcohol using ball mill for 1 hour. The ratio of ball to powder is 10:1. The hydraulic press of 150kN was used to compact of copper, nickel, and chromium. Three different compaction pressureswere applied with 250, 300 and 350MPa for preparing the electrode. Constant hydraulic forces were applied for 10min using punch and then pallet was ejected using lab press. The compacted cylindrical billet dimension with 10mm diameter and 20mm length were obtained. The tubular furnace was brought to vacuum and the compacted specimens were heated in tubular furnace containing argon atmosphere and the heating rate for sintering is 10°C per min. The furnace temperature for sintering wasdone at 800°C and further, it was cooled down inside the furnace to achieve homogenous mixture of powder materials.

2.2. Surface modification of strenx steel

The sintered alloys were coated on thesurface of strenx steel plate. The substance compositions of the strenx steel were shown in Table 1.The positive polarity was applied to sintered electrode.The process parameters were shown in Table 2. By varying parameters, alloycharacteristics were analyzed. An L_9 orthogonal array was used for conducting the experiment which is shown in Table 3. Surface roughness was measured using Mitutoyo SJ-400 tester over the alloyed surface. The surface topology of the modified layer was investigated using SEM with Energy Dispersive X-Ray Spectroscopy (EDS). Further, the alloyed surface was analyzed using atomic force microscopy.

2.3. Wear measurement

The pin substrates were alloyed by using three electrodes namely Cu-10Ni-2 wt. %, Cu-10Ni-4 wt. %, and Cu-10Ni-6 wt %. Wear test was conducted using tribometer of American Society for Testing and Materials (ASTM): G99-05. The pin was made to rotate against EN31 steel disc of 100mm diameter. The weight loss of the pin was measured using 0.1 mg precision electronic weighing balance.

Table 1. Substance composition of Strenx steel.

C	Si	Mn	P	S	Cr	Cu	Ni	Mo	B	Fe
0.20	0.50	1.60	0.020	0.010	0.80	0.3	2	0.70	0.005	remaining

Table 2. Control factors and their levels.

Machining Condition	Description
Work piece	Strenx 900 Steel
Electrode material	Cu-Ni-Cr
Dielectric	EDM oil 30
Polarity	Strenx 900 rectangular plate: Negative Copper tool: Positive
Process parameter with their levels	
Peak current	3A, 6A, 9A
Compaction pressure	250 Mpa, 300Mpa, 350Mpa
semi sintered electrode	Cu-10Ni-Cr_x
Constant Parameters	
Gap Voltage (V)	50
Duty factor	50%
Spark Gap	0.10mm
Flushing pressure	0.8 kg/cm^2

3. Results and Discussion

3.1.Surface morphology of alloyed surface

Figure 1a-b shows the surface morphology of alloyed surface. The lesser amount of nickel and chromium were deposited over the surface of strenx steel. The electrode material suspended in EDM 30 oil moved to the surface while applying peak current. Better surface roughness was obtained due to the positive polarity of the electrode and current density on anode is smaller than that on the cathode due to the superior radius of discharge mark on the anode[13]. From Figure 1b, it was evident that higher current discharge (9A) has produced craters along with deposition of nickel

Table 3. Experimental observations.

S.No	Wt. % of Cr	Compaction pressure MPa	Peak current A	SR µm	MTR mg/min
1	2	250	3	5.9177	91.60
2	2	300	6	6.5000	107.00
3	2	350	9	6.7611	110.40
4	4	250	6	6.6777	190.00
5	4	300	9	7.1000	208.50
6	4	350	3	7.6111	230.80
7	6	250	9	7.4377	281.23
8	6	300	3	7.9494	311.20
9	6	350	6	8.3711	329.70

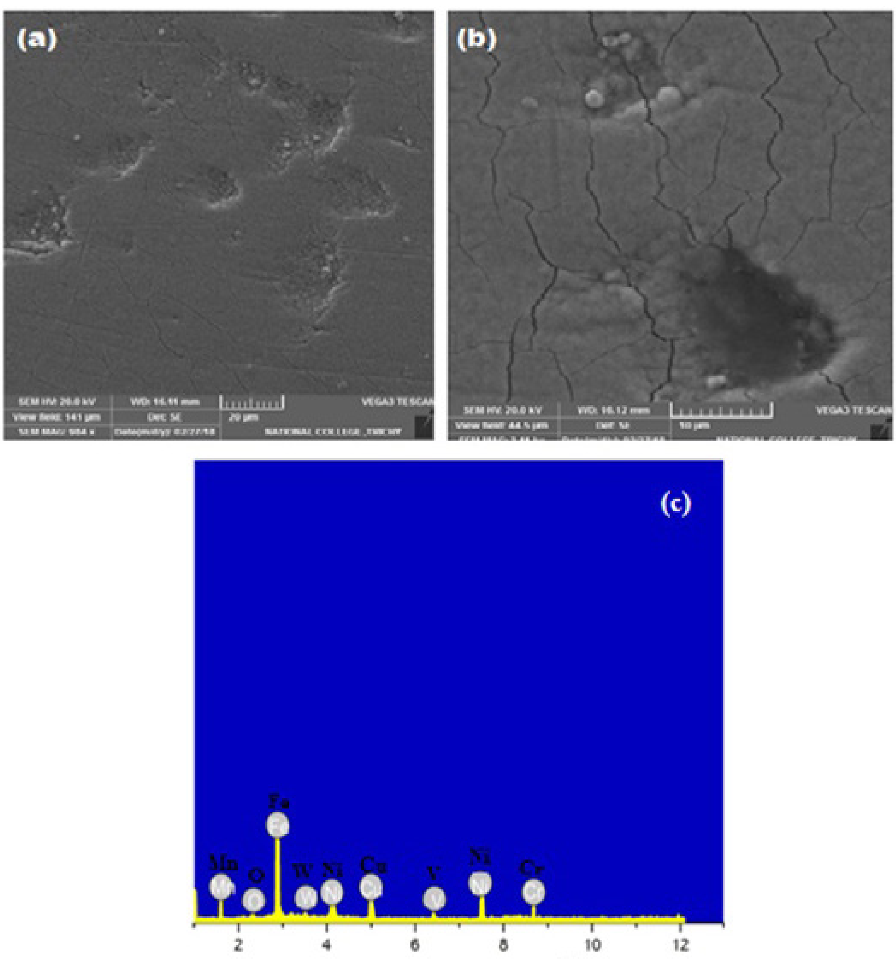

Figure 1. Scanning Electron Microscope (SEM) analysis of alloyed surface by Cu-10Ni-2Cr at (a) peak current of 6A, compaction pressure of 300 MPa and 2 wt.% Cr (b) peak current of 9A, compaction pressure of 250Mpa and 6 wt.% Cr(c) EDS result of modified layer using Cu-10Ni-2Cr.

and chromium. The formation of surface crack was obtained due to immediate quenching of fused metal in localization area. Figure 1c shows EDS result of the alloyed layer using Cu-10Ni-2Cr. The nickel depositions were confirmed with corresponding peaks of nickel adjacent to ferrous peak.

Figure 2 shows the SEM and EDS results of alloyed layer. The evidence of materials deposited from tool electrode wasshown in EDS results. It was evident that surface of strenx steel was coated with nickel and chromium. EDS results has confirmed the deposition of chromium and nickel over surface. Higher percentage of Cr has improved the alloy content andusing semi sinteredCu-10Ni-6Cr electrode, Cu powder improves binding strength as well as conductivity for EDM machining. The addition of alloying element has both lower electrical conductivity as well as thermal conductivity in powder metallurgy electrode. The rates of erosion wasincreased and as a result, tool material got deposited on the substrate[14].

3.2. Surface morphology of atomic force microscopy

Figure 3a shows the surface topology obtained at peak current of 3A and compaction pressure of 250MPa. Atomic force microscopy results revealed better surface finish which

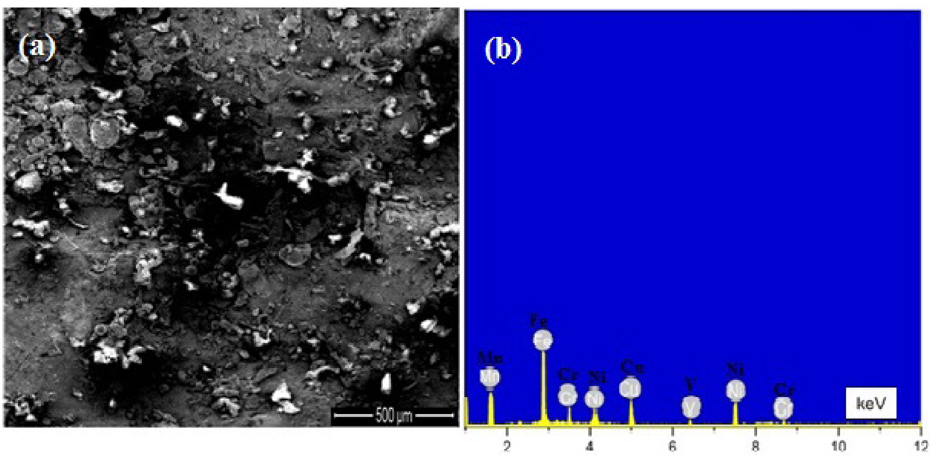

Figure 2. (a) SEM and (b) EDS result of the alloyed layer using Cu-10Ni- 6Cr at peak current of 9A, compaction pressure of 250Mpa and 6 wt.% Cr.

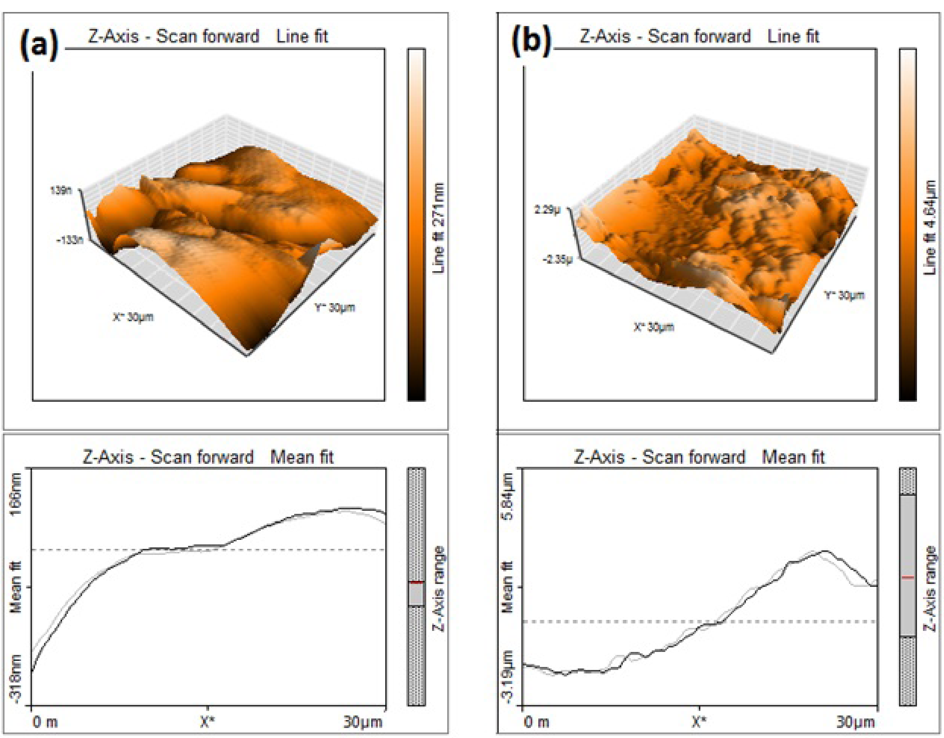

Figure 3. Atomic force microscopy results for the coated layer obtained (a) 3A, compaction pressure of 250 MPa and Cu-10Ni-2% Cr electrode (b) 6A, compaction pressure of 350 MPa and Cu-10Ni-6% Cr electrode.

has no peaks and troughs. This finish was obtained due to the two reasons (a) the low compaction pressure which results in loose bonding of electrode particles and (b) nickel prevents secondary arcing which results in uniform discharge causes lower surface roughness[15].

Figure 3b shows the surface topology obtained at peak current of 6A and compaction pressure of 350MPa. At this set of parameters, high surface roughness was obtained due to deposition of more alloying elements of nickel and chromium.The reverse polarity of electrode causes to form more discharge energy which results in more alloying particles of electrode to fall on the work piece. These alloyed particles become bonded to the work piece during cooling by flush system[16]. High chromium content released from electrode material forms bridging effect.

3.3. ANOVA results

From Table 4 and 5, Analysis of variance (ANOVA) results revealed that chromium content in electrode is the foremost in affecting surface roughness as well as material transfer rate, followed by compaction pressure. Therefore, chromium content and compaction pressure are the significant parameters towards SR and MTR. The higher chromium content improved MRR has reduced the electrode wear and enhanced the surface roughness[17]. The influential percentage contribution of chromium content, compaction pressure and peak current towards SR was found to be73.71% and 25.93% and it's shown in Table 4. Table 5 shows ANOVA results of material transfer rate. The influential percentage contribution of chromium content, compaction pressure and peak current towards SR were found to be 96.56% and 3.03% respectively. R- Squared values were closer to unit which makes model significant. Higher Material transfer rate was obtained at 9A, 350 MPa using 6% of chromium.

3.4. Wear measurement

Figure 4 shows the wear characteristics of prepared Cu-10 Ni-Cr_x electrode. PM Cu-10 Ni without chromium content shows high wear compared to Cu-10 Ni-Cr_x (x=2, 4 and 6 wt. % Cr). The wear loss increase steadily with an increase in sliding speed from 2m/s to 6m/s. Wear loss for PM Cu-10 Ni-Cr_0 is high compared to the other alloy added with chromium. Wear loss for Cu-10 Ni-Crincreases linearly with an increase in sliding speed from 2m/s to 4m/s. With

Table 4. Variance analysis for SR.

Source /SR	DF	SS	MS	F	P	%
% of Cr	2	3.49656	1.74828	612.33	0.002	73.71
Compaction pressure	2	1.22997	0.61499	215.40	0.005	25.93
Peak current	2	0.01107	0.00554	1.94	0.340	00.23
Error	2	0.00571	0.00286	--	--	00.13
Total	8	4.74332	--	--	--	100
S= 0.0534336	R-sq= 99.88%		R-sq(Adj)= 99.52%		R-sq(Pred)= 97.56%	

Table 5. Variance analysis for MTR.

Source /MTR	DF	SS	MS	F	P	%
% of Cr	2	62696.7	31348.3	1123.06	0.001	96.56
Compaction pressure	2	1968.0	984.0	35.25	0.028	03.03
Peak current	2	208.2	104.1	3.73	0.211	00.32
Error	2	55.8	27.9	--	--	00.09
Total	8	64928.7	--	--	--	100
S= 5.28330	R-sq= 99.91%		R-sq(Adj)= 99.66%		R-sq(Pred)= 98.26%	

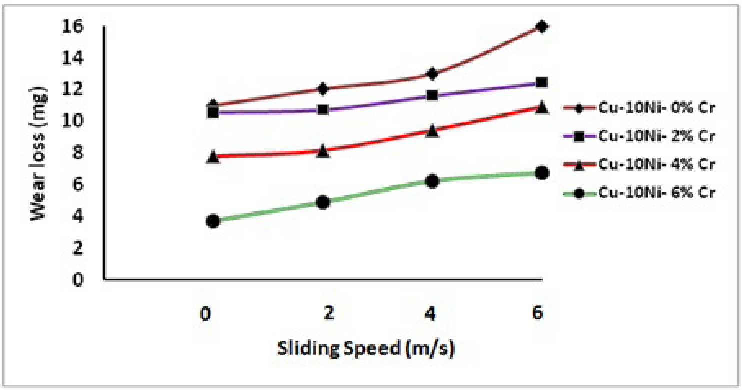

Figure 4. Wear behaviors of Cu-Ni-Cr.

subsequent increase in sliding speed from 4m/s to 6m/s, there were no substantial loss in wear due to increase in chromium content. Sliding speed was the predominant factor to affect the wear rate in powder metallurgy based copper nickel alloy[18]. The wear characteristics were found in magnesium alloy at different temperature conditions[19].

4. Surface Roughness

The desirable SR value is found out from Taguchi approach. Based on the experimental objective, the SR value should be minimized. The surface roughness and its properties were enhanced through material deposition to the base alloys[20,21]. As per condition of the outcome, the lower the better is considered for SR. According to the criteria, Signal to Noise (SN) ratio and means are computed and it's shown in Table 6. SN ratio was used to reduce the error in design of experiment and uncertainty factors[22]. The quality characteristics and its effect on the responses were depends on SN ratio[23]. The significant factor of the process and its predicted model were controlled by SN ratio[24].

Figure 5 shows that the main causes of SN ratio on SR. From the graph, the desirable SR value is attained at the level of $A_1B_1C_3$. Therefore, the minimum SR is attained at percentage of chromium of 2%, compaction pressure of 250MPa and peak current of 9A.

5. Material Transfer Rate

The aim of the investigation is to increase the material transfer rate. Hence, maximize the better criteria waschosen to achieve the MTR. Based on this condition, the mean and SN ratios are estimated and it's listed on the Table 7. The optimal MTR is shown in Figure 6. The desirable MTR is obtained at $A_3B_3C_1$. Therefore, the maximum MTR is achieved at percentage of Cr of 6, compaction pressure of 350 MPa and peak current of 3A.The effect of compaction pressure on material transfer rate were investigated for

Table 6. Calculated SN ratio and means for SR

	SN ratio			Means		
Level	% of Cr	Compaction pressure	Peak current	% of Cr	Compaction pressure	Peak current
1	-16.10	-16.45	-17.03	6.393	6.678	7.159
2	-17.05	-17.10	-17.07	7.130	7.183	7.183
3	-17.96	-17.56	-17.02	7.919	7.581	7.100
Delta	1.86	1.11	0.05	1.526	0.903	0.083
Rank	1	2	3	1	2	3

Table 7. Calculated SN ratio and means for MTR.

	SN ratio			Means		
Level	% of Cr	Compaction pressure	Peak current	% of Cr	Compaction pressure	Peak current
1	40.23	44.60	45.45	103.0	187.6	211.2
2	46.41	45.61	45.51	209.8	208.9	208.1
3	49.73	46.16	45.41	307.4	223.6	200.0
Delta	9.51	1.56	0.10	204.4	36.0	11.2
Rank	1	2	3	1	2	3

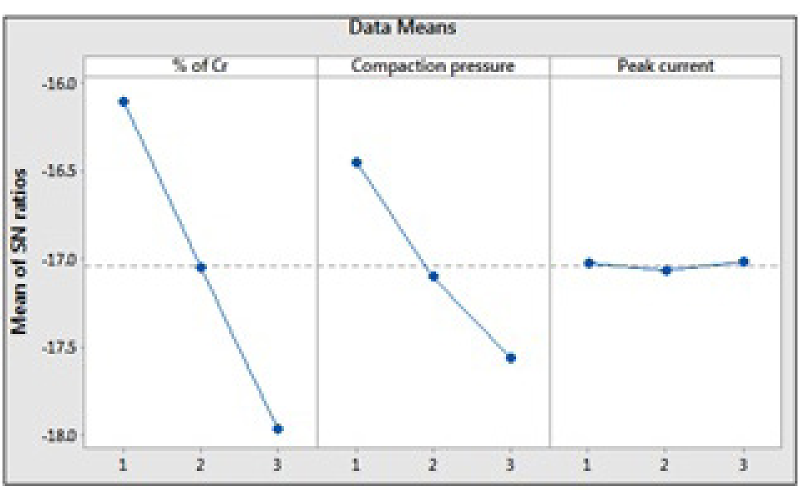

Figure 5. Desirable factor for SR.

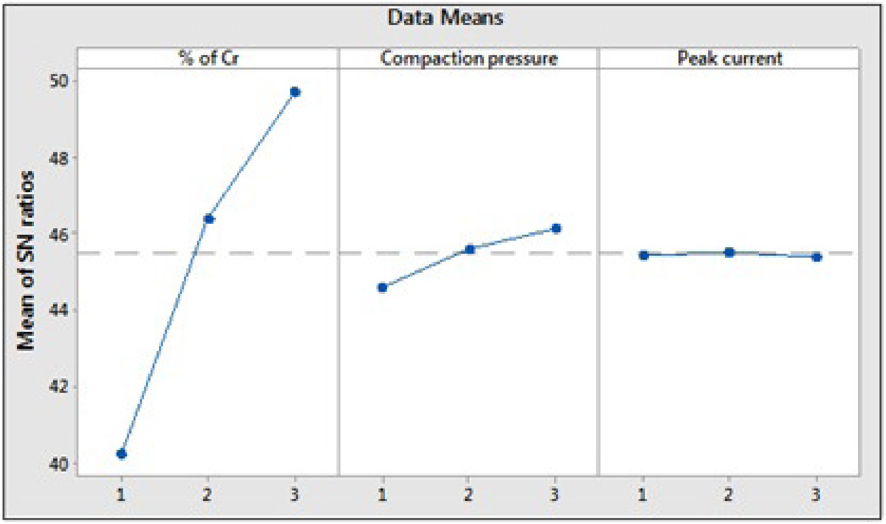

Figure 6. Desirable factor for MTR.

different alloys with forming temperature conditions[25]. The processing parameters and dynamic compaction system were played an essential role in material transfer rate[26].

6. Conclusion

- Chromium, copper and nickel were deposited successfully over Strenx 900 steel using EDA process.
- Higher material transfer rate was obtained at 9A, 350A and 6% chromium using Cu-10 Ni-Cu_6 electrode.
- EDS results revealed the presence of nickel, chromium and copper over Strenx steel 900.
- Strenx steel surface alloyed using Cu-10 Ni-Cu_6 electrode showed less wear compared to the other synthesized electrode. Additon of chromium content in PM electrode has enhanced the wear resistance.
- Higher material transfer rate yielded in higher surface roughnesswere witnessed by peaks and troughs in atomic force microscopy analysis.
- Chromium content is the foremost factor in influencing material transfer rate and surface roughness followed by compaction pressure.
- From variance analysis, percentage of chromium was identified with dominant factor for SR (73.71%) and MTR (96.56%).
- From Taguchi approach,the minimum SR was attained at percentage of chromium of 2%, compaction pressure of 250Mpa and peak current of 9A.
- The maximum MTR is achieved at percentage of Cr of 6, compaction pressure of 350 MPa and peak current of 3A.

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