



Research Paper / Makale

**Investigation of Fume Formation Rate in SMAW of 316L Stainless Steel
with Different Electrodes Using Taguchi and Anova**

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Abstract: Welding is one of the most utilized joining techniques in heavy industry and manufacturing sector due to its ease of application and strength. 316L grade stainless steel is mainly used in chemical, petro-chemical, food, paper, paint and shipbuilding industries as well as dairy equipment. Arc welding processes are preferred in joining of stainless steel and shielded metal arc welding is widely used in this respect along with gas metal arc welding. There are some drawbacks of welding despite many advantages. Welding is defined as a hazardous process in terms of occupational safety and health and the environment because of toxic fume and noxious gases emitted. In this study, Taguchi design of experiment was utilized and shielded metal arc welding of 316L grade stainless steel was realized using electrodes with same classification from two different brands with different current parameters. Fume formation rates for each experimental condition were measured and results were evaluated using Taguchi signal to noise ratios and analysis of variance.

Keywords: 316L stainless steel, SMAW, fume formation rate, Taguchi, ANOVA

**316L Paslanmaz Çeliğin Farklı Elektrotlar ile Yapılan Örtülü Elektrot Ark
Kaynağında Duman Oluşum Hızının Taguchi ve Anova ile İncelenmesi**

Özet: Kaynak, kolay uygulanabilirliğinden ve mukavemetinden dolayı, imalat sektörü ve ağır sanayide en çok kullanılan birleştirme yöntemlerinden birisidir. 316L kalite paslanmaz çeliklerin başlıca kullanım alanları kimya, petro-kimya, gıda, kağıt, boya ve gemi imalatıdır. Paslanmaz çeliklerin kaynağında ark kaynak prosesleri tercih edilmektedir ve gazaltı kaynağının yanında örtülü elektrotla ark kaynağı da sıklıkla kullanılmaktadır. Kaynak prosesinin avantajlarının yanında bazı dezavantajları da vardır. Kaynak, toksik duman ve sağlığa zararlı gazlar oluşturduğu için iş sağlığı ve güvenliği ile çevre açısından tehlikeli bir proses olarak tanımlanmaktadır. Bu çalışmada, Taguchi deneysel tasarımı oluşturulmuş ve iki farklı markanın aynı sınıflandırmaya sahip elektrotları, farklı akım parametreleri kullanılarak 316L paslanmaz çeliğin örtülü elektrot ark kaynağında kullanılmıştır. Her deney şartındaki duman oluşum hızları ölçülmüş ve sonuçlar Taguchi sinyal-gürültü oranı ve varyans analizi ile değerlendirilmiştir.

Anahtar kelimeler: 316L paslanmaz çelik, örtülü elektrot ark kaynağı, duman oluşum hızı, Taguchi, ANOVA

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1. Introduction

Welding is the most common joining operation used in shipbuilding sector as well as other industrial manufacturing processes. Although there are many different types of welding, shielded metal arc welding is one of the most frequently used methods amongst all for both low carbon and stainless steels.

Welding has the biggest share in assembly processes with approximately 48-50 percent. In spite of the major material of a ship is steel, aluminum and other materials are used for some superstructures like the deckhouses and other specific areas within the ship [1]. In ship building, stainless steel materials are mainly used in manufacturing of ship warehouses. Various welding electrodes are used for welding metal parts in shipbuilding industry. Depending on the type of electrode, different types and amounts of emissions are generated [2]. Chemical composition of welding fume and the exposures must be determined experimentally in order to develop preventive measures against the hazards of welding fume to workers' health and the environment [3]. Welding fume is produced by evaporation and condensation of metallic elements in air. Amount of emissions may vary according to welding processes and parameters. Composition of fume varies with the contents of the electrode, parameters and work piece and toxic fume released contains potential hazards to human health. Although, worker exposure is usually prevented by ventilation and personal protective equipment, detection of environmental exposure is much more difficult [4].

Sowards et al. researched the effect of heat input on fume generation rates in some SMAW electrodes [5]. Kura, has determined that fume amount of flux-cored electrode welding is much more than other welding methods [6]. Welding fume particles less than 1mm in diameter cause the greatest health hazard due to their ability to penetrate deep into the lungs [7]. Hazardous metals listed in the 1990 Clean Air Act Amendments that have been detected in welding fume include manganese, nickel, chromium, cobalt and lead. Additionally, the hexavalent form of chrome (Cr^{+6}) is also found in some welding fume emissions. The emissions of toxic air contaminants during welding have potential adverse human health impacts [4]. Sowards et al. studied characterization of welding fume particles of SMAW electrodes [8]. Matczak et. al., numerically calculated soluble and insoluble Cr^{+3} and Cr^{+6} compounds inside welding fume [9]. Stopford, has researched welding fume particle sizes and chemical characteristics [10]. Amount of welding fume varies with the electrodes, methods, shielding gases, welding conditions and welder's skill. Mostly used welding materials include manganese, silicon, chromium and nickel. Chromium and nickel fumes are accepted in the carcinogenic class. High exposure to manganese can cause neurological disorders and discomforts to workers.

It is not clearly proven in epidemiologic studies that welding fume cause lung cancer. Investigation of possible correlation is ongoing quite broadly between welding profession and lung cancer cases and deaths. It is seen that high risk of cancer are shown in studies on welders. International Agency for Research on Cancer (IARC) reported in 1990 that "welding fume is probable carcinogen substance" [11]. Metal fume fever is also a possibility after exposure to manganese fume. Chronic manganese poisoning, characterized by a severe disorder of the nervous system, has been reported in welders working in confined spaces on high-manganese steels [12].

2. Experimental Study

In this study, experiments were designed using Taguchi method, which is one of the most reliable designs of experiment methods. Taguchi design of L4 orthogonal array was implemented and welding trials were run for three times. Table 1 shows two process factors (i.e. electrode type and current) and two levels, which were used to form L4 orthogonal array. Current values (level 1 and level 2) were decided so that the values would reflect the highest and lowest current in working

range given by the manufacturers. Welding speed factor was not included in the experiments since Mert et al. [13] has shown that welding speed was an insignificant factor in terms of fume formation rate in SMAW.

Table 1. Experimental factors and levels

Symbol	Factor	Level 1	Level 2
A	Electrode type	LR32	LR12
B	Current (A)	80	120

Fume emission experiments have been realized inside a fume chamber (Figure 1) designed according to EN ISO 15011-1:2009 [14]. X2CrNiMo17-12-2 (EN 10088-1) stainless steel round plates with diameter of 290 mm were used in the experiments and these plates were welded with E16 12 3 LR 32 (EN ISO 3581) and E16 12 3 LR 12 (EN ISO 3581) covered electrodes with 3.20 mm diameter for 30 seconds. Welding power source was Lincoln Electric Invertec V260-S. Chemical composition of base metal and the electrodes are given in Table 2. Fume was captured on round Sartorius Stedim MGA glass fiber filters with 240 mm diameter. Filters were stored in a furnace at 110°C for at least 1 hour before and after the experiments. Shimadzu BL-320H electronic balance was used to weigh filters and electrodes.



Figure 1. Fume chamber

Table 2. Chemical composition of X2CrNiMo17-12-2 stainless steel and E16 12 3 LR 32 and E 19 12 3 LR12 stainless steel covered electrodes (% wt)

Material/Electrode	C	Mn	Si	Cr	Ni	Mo
X2CrNiMo17-12-2	≤0.03	2.0	1.0	17.0	12.0	2.50
E16 12 3 LR 32 electrode	≤0.04	0.80	0.70	19.0	12.0	2.60
E 19 12 3 LR12 electrode	≤0.03	0.80	0.70	17.0	11.0	2.90

3. Results and Discussion

After the welding experiments were realized according to L4 Taguchi design and repeated three times, fume accumulation on filters were weighed and fume formation rate was calculated. Table 3 presents Taguchi design and mean FFR measurements.

Table 3. L4 experimental set and FFR measurements

Factors and levels			Output	
Run	Electrode type	Current	FFR (g.min ⁻¹)	S/N ratio (dB)
1	1	1	0.155	16.1934
2	1	2	0.258	11.7676
3	2	1	0.147	16.6537
4	2	2	0.251	12.0065

Experimental data were analyzed using signal to noise (S/N) ratio and the analysis of variance (ANOVA) methods by using Minitab 17 software. It is better to have smaller fume formation rate in welding in terms of environmentally friendliness and occupational safety and health, smaller is better equation was chosen (Eq. 1) in S/N calculations. Here, n is the number of repeated experiments, Y is the measured value of the response variable.

The lower ---- the better:

$$S/N = -10\log((\sum Y^2)/n) \quad (1)$$

Table 4 shows response table for S/N ratios. S/N ratios in Taguchi method are used to investigate the significance of the factors. Higher S/N ratios yield to the aim, which is lower FFR in this study. Table 4 and Fig. 2 depict that current has the highest effect on FFR and is followed by electrode type. It is understood that FFR is minimum at second level of electrode type (A2) and first level of current (B1). Therefore, optimum design parameter combination is A2B1. Since this combination was included L4 orthogonal array, confirmation test was not needed.

Table 4. Response table for S/N ratios

Level	A	B
1	13.98	16.42
2	14.33	11.89
Delta	0.35	4.54
Rank	2	1

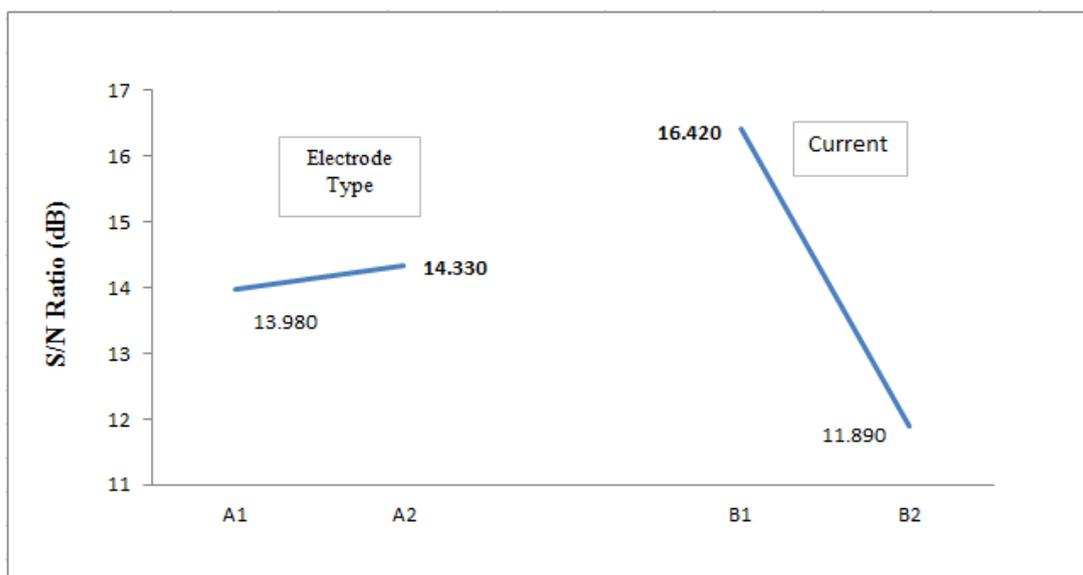


Figure 2. S/N ratios of factor levels for FFR

ANOVA analysis was performed to investigate the significance of the factors on FFR. ANOVA results were based on general linear model and are given in Table 5. P-value should be equal or less than 0.05 with 95% confidence level. P-values for both factors were less than 0.05. Therefore, electrode type and current factors had statistically significant effect on FFR. Percentile effects of electrode type and current were 99.48% and 0.52%, respectively. Coefficient of determination (R-sq (adj)) in ANOVA analysis was found to be 99.99%.

Table 5. Analysis of variance results for FFR

Source	Degree of Freedom	Adj SS	Adj MS	F-value	P-value	% Effect
A	1	0.000056	0.000056	225.00	0.042	0.52
B	1	0.010712	0.010712	42849.00	0.003	99.48
Error	1	0.000000	0.000000			0.00
Total	3					100

4. Conclusion

According to experimental results and Taguchi and ANOVA evaluation, main conclusions can be summarized as follows. In both electrodes, higher current values yielded higher FFR. Current was the most significant factor and the effect of the type of the stainless electrode on FFR was negligible. FFR results obtained with the use of electrode type E 19 12 3 LR12 was smaller compared with E 19 12 3 LR32 for both current values. Not only E 19 12 3 LR32 type electrode has higher FFR but also a composition with higher chromium and nickel, which are widely accepted as toxic substances in terms of OSH, making this electrode much more prone to be potentially dangerous for human health as well as the environment. Therefore, it is advisable to select electrodes with lower FFR and lower toxic elements, provided that welding design criteria are met.

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