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Optimization of Process Parameters of Electron Beam Welded Fe49Co2V Alloys

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ABSTRACT

Electron beam welding has shown a remarkable job in the space industry for welding of components. It is performed under a vacuum environment that eliminates foreign matter such as hydrogen, oxygen, and other gases. Joining of similar and dissimilar materials is the main advantage of electron beam welding with high depth to width ratio as well as sharp focus at the point where parts are to be welded. EBW reduces the HAZ (heat affected zone), making it one of the most acceptable welding processes. In this study, evaluation of the effect of joining parameters on the mechanical strength and hardness is conducted using Minitab software. The strength of the electron beam weld varies with welding parameters. Therefore, correct and optimized parameter selection imparted the highest welding strength. Some welding parameters directly affect weld strength; those were judiciously selected for our experiments. Therefore, 3x3 arrays were selected for investigation on the microhardness and ultimate tensile strength of $Fe_{49}Co_2V$. Three levels and four factors are chosen for analysis. The input parameters are selected as Accelerating Voltage (KV), Welding Speed (mm/min), Beam Current (mA), and Focus Current (mA). This study reveals the maximum welding strength obtained at High Voltage (55 KV), High Beam current (7 mA), Moderate Speed (20 mm/min), and moderate focus current (2365 mA). Similarly, the microhardness obtained at a High Voltage (55 KV), High beam current (7 mA), high welding speed (30 mm/min) and minimum focus current (2210 mA).

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1. INTRODUCTION

Electron beam welding is a fusion welding process. The high-velocity electrons strike the surface of the workpiece, and heat is produced. During the process, the kinetic energy of an electron is converted into thermal energy [1]. This thermal energy is utilized to fuse the metal. The whole process is carried out in a high vacuum to avoid deflection of electron and to prevent the surface of weld and workpiece with oxide contamination. The various components of EBW are tungsten filament, cathode, and an anode electrode, focusing coil, deflection coil, etc. [2]. The tungsten filament is heated to emit the electron. The acceleration of the emitted electron takes place by a high voltage between anode and cathode. Figure 1 shows the diagram of Electron Beam Welding. The welded area is minimal during welding, keyhole weld is created by electrons beam consisting of a molten zone, and this zone is supported by vapor [3]. Quick solidification of the weld part takes place when the beam is switched off quickly, and it causes weld defects. So, a small overlap is formed on a circular weld to ensure 360-degree fusion [4]. With the help of a modern electron beam welding machine (having a high vacuum and high voltage), a depth of 7.5 cm in steel and 15 cm in aluminum can be welded [5]. Figure 2 shows the energy transformation of the electron beam inside the workpiece. The kinetic energy of the electron beam is dissipated through heat when the electron beam is highly accelerated using electrode[1]. Primary electrons get backscattered while secondary

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[1] https://www.mech4study.com/2017/04/electron-beam-welding-principle-working-equipment-application-advantages-and-disadvantages.html

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electron scattered along with x-rays[1]. The electron beam penetrates only a few microns into the workpiece, but its kinetic energy is transmitted to the workpiece in the form of heat. This high energy heat vaporizes the metal, making a keyhole on the workpiece [6]. As the electron beam moves along the joining line, the weld is formed by the combination of these three effects, 1. Metal on advancing side vaporizes and condenses to form molten metal at trailing edge, 2. Molten metal flows from leading edge to trailing edge, 3. The molten metal fills the holes and solidifies [7].

In this work, electron beam welding is used to join the iron alloy. Hardness and tensile properties of the welded part is investigated. It is found that weldments of the iron alloy fracture during tensile testing because of the high hardness and tensile strength. The aim is to study the 3.0 mm Fe_4Co_2V welded alloy by electron beam welding (EBW) and also the behavior between Microhardness, Tensile strength, and welding parameters.

2. EXPERIMENTATIONS

2. 1. Equipment The experiment was designed based on the design of experiment techniques using Minitab software to examine the influence of major impacting parameters on the strength of electron beam welded joint. To find out tensile strength, microhardness of the electron beam welded joint of $Fe_{49}Co_2V$ alloy and the optimum value of input factors of the welding machine, which gives the optimum tensile strength and micro-hardness. 1cu meter electron beam welding machine of TECHMETA is used for welding specimens. The experiment was performed on an electron beam welding machine, as shown in Figure 3. The specification of the electron beam welding machine is mentioned in Table 1. The machine was equipped with a modern vacuum chamber and adjustable voltage, beam current and welding speed.

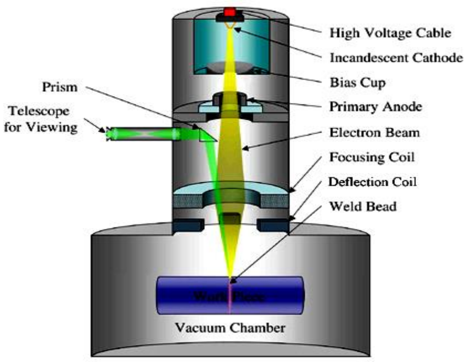

Figure 1. Electron Beam Welding Machine [9]

[1]https://mountainscholar.org/bitstream/handle/11124/17068/Yost_mines_0052N_10655.pdf?sequence=1.

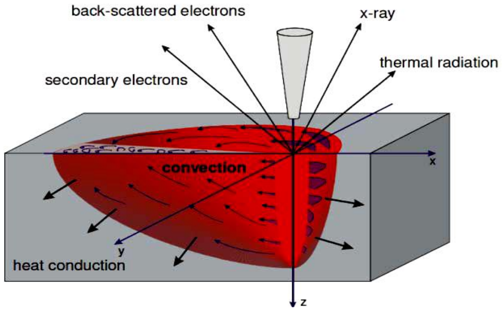

Figure 2. EB energy transformation inside the workpiece [8]

2. 2. Workpiece Preparation The cobalt-iron (CoFe) alloys find application where minimum weight and high flux density are required. It comes under ASTM A801-14 Standard, i.e., Specification for Wrought Iron-Cobalt High Magnetic Saturation Alloys. The size of the $Fe_{49}Co_2V$ alloy test plate used in the experiment was 150 × 40 × 3 mm. The alloy compositions are as shown in the following Table 2.

Figure 3. Electron Beam Welding Machine (Techmeta) *(courtesy: HAL Korwa)*

TABLE 1. Specification of Electron Beam Welding Machine

S.No.	Elements	Discrription
1	Vacuum chamber	350 × 360 × 400 mm
2	Chamber pumping system	Oil diffusion pump (backed by a rotary vane pump)
3	E.B gun system	heated cathode gun (60 KV) with a dedicated vacuum system
4	Manipulation system	Vertical gun movement, the rotary manipulator (radial weld), the rotary manipulator (facial weld)
5	Gun vacuum	$1\times10^{-}$ m bar
6	Accelerating Voltage	20 to 60KV
7	Beam current,	0 to 100 mA
8	Welding speed	0 to 500mm/min

TABLE 2. Chemical composition of Fe49Co2V

Components	**Co**	**V**	**Fe**
Weight %	49%	2%	Balance

This alloy is widely used in aircraft, automobile, and electrical manufacturing industries where soft magnetic material with saturated magnetic indication property is required. The base material surface is polished before welding with sandpaper, and it is pickled in acetone. The base material size is 150 × 40 × 3 mm, which initially sectioned into two parts of size 75 × 40 × 3mm each. Then edge preparation was done to maintain a minimum gap between two plates, and it is welded along the lateral direction (butt joint). The beam was focused on the welding spot. The weld spot was adjusted with the viewing camera. A total of 9. of samples were prepared to fulfill the Taguchi L9 orthogonal array of investigation [9].

During any experimental analysis, input data/factors affecting value selection is essential because all affecting factor independently affects the result differently than in the combination of all factors. Therefore, it becomes crucial to select the affecting factors in such a combination that the effect of all factors will be equally justified in the result. For this selection, Taguchi Orthogonal array method helps in a very easy manner. A small set from all the possibilities is selected for reducing the number of experiments to a practical level [10]. Taguchi constructed the design guidelines for factorial experiments that cover many applications. For understanding the effect of 4 independent factors, each having 3-factor level values. L9 array assumes that there is no interaction between any two factors. In some situations, no interaction model assumption is valid. There are some situations where there is clear evidence of an interaction. In this work, 4 factors are input variables of EBW machine i.e. Factor 1: Beam Current, Factor 2: Accelerating Voltage, Factor 3: Weld Speed, Factor 4: Focus Current. Considering these all four factors and by arranging in 3 levels as per Taguchi Orthogonal array following array will be created Table 3:

The above Array shows that for better analysis by considering four input factors of machine 9, different tests need to be performed i.e., 9 samples should be prepared. By considering the Input factors and specifications of EBW machine, the different factors of Taguchi Orthogonal array for the experiment presented in Table 4. The value of beam current, voltage, and travel speed were selected according to the experimental experience of EBW welder and previous research work done in the area of electron beam welding process.

The geometry of the joint produced by EBW is illustrated in Figure 4. The assembly provided a butt joint of 3.0 mm thick.

TABLE 3. Taguchi Orthogonal Array 4 factor and 3 Level (L9)

Experiment No.	**Beam Current (mA)**	**Voltage (KV)**	**Weld Travel Speed(mm/min)**	**Focus current (mA)**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

For calculating the tensile strength of the material after the Electron beam welding, the tensile samples were prepared and tested on UTM machine. It is the maximum amount of tensile stress before the failure of the material [11]. In this stage of Mechanical testing, welded samples were fabricated as per standard ASTM E 8/E 8M to form the samples in the tensile test. All samples were fabricated to the standard size on the numerically controlled wire-cut machine to make a specimen of tensile testing, as shown in Figure 5.

TABLE 4. Taguchi Orthogonal Array with selected Factors

Experiment No.	**Beam Current (mA)**	**Voltage (KV)**	**Weld Travel Speed (mm/min)**	**Focus current (mA)**
1	6	55	30	2435
2	6	45	20	2210
3	6	50	10	2365
4	5	55	20	2365
5	5	45	10	2435
6	5	50	30	2210
7	7	55	10	2210
8	7	45	30	2365
9	7	50	20	2435

Figure 4. Welded Sample

Figure 5. sample fabricated as per standard ASTM E 8/E 8M for Tensile testing

3. RESULT AND DISCUSSION

3. 1. Microhardness and Tensile Testing Microhardness testing on all 9 samples are done under the load of 5 Kgf, and the corresponding result of microhardness values (HRC & HV) of each sample is given in Table 5. The microhardness values are measuerd at the weld bead along the weld line. The highest hardness was 29.5 HRC (298 HV) at a beam current 7 mA, 55 kV, and weld travel speed was 10 mm/min. The experimental values obtained from the tensile testing of the welded are illustrated in Table 6. The tensile test is performed on the Universal testing machine, for samples, and the results are precisely calculated.

TABLE 5. Test Result of Microhardness of welded specimen

S.No.	Beam Current (mA)	Voltage (kV)	Weld Travel Speed (mm/min)	Focus current (mA)	HRC	HV
1	6	55	30	2435	27.4	282
2	6	45	20	2210	25.2	267.7
3	6	50	10	2365	22.6	251.7
4	5	55	20	2365	27.0	283.0
5	5	45	10	2435	25.3	273.6
6	5	50	30	2210	25.8	270.9
7	7	55	10	2210	29.5	298
8	7	45	30	2365	27.5	283
9	7	50	20	2435	26	278

TABLE 6. Test Result of Tensile Strength of welded specimen

Experiment No.	Beam Current (mA)	Voltage (KV)	Weld Travel Speed (mm/min)	Focus current (mA)	Tensile strength (N/mm^2)
1	6	55	30	2435	127.7
2	6	45	20	2210	69.4
3	6	50	10	2365	316.6
4	5	55	20	2365	477.7
5	5	45	10	2435	27.77
6	5	50	30	2210	50
7	7	55	10	2210	505.55
8	7	45	30	2365	200
9	7	50	20	2435	425

3. 3. Analysis with Minitab Software This study was performed on Minitab Taguchi analysis and the results of microhardness and tensile strength with the effect of input parameters are generated. The results of microhardness in HV and HRC are experimentally calculated and analyze with software for the optimization of data. Taguchi design analysis of all 4 factors over microhardness can be easily understood with the analyzed graph of hardness presented in Figure 6 and can be concluded as: If Voltage is considered only as an affecting factor, then welding at 55KV will generate max hardness, and 50 KV will generate minimum hardness.

If weld speed is the only affecting factor, then welding at 30mm/min will generate max hardness, and 10 mm/min will produce minimum hardness. If Focus Current is considered only as an affecting factor, then welding at 2210 mA will generate maximum hardness, and 2365 mA will produce minimum hardness. It was observed by the analysis on the Taguchi method that welding speed, beam current, and voltage should be high, but the value of focusing current should least for optimal solution obtained by the Minitab analysis. If all four factors are considered, then microhardness will be maximum at Voltage 55 KV, Beam Current 7 mA weld speed 30 mm/min & focusing current 2210 mA.

All four factors over Microhardness in HV:

Taguchi design analysis of all four factors over Microhardness can be easily understood with the analyzed graph of Microhardness (HV) presented in Figure 7 and it can be concluded as: If Beam Current is considered only as an affecting factor then welding at 7 mA will generate max hardness and 6 mA will generate minimum hardness. If Voltage is considered only as an affecting factor, then welding at 55 KV will generate

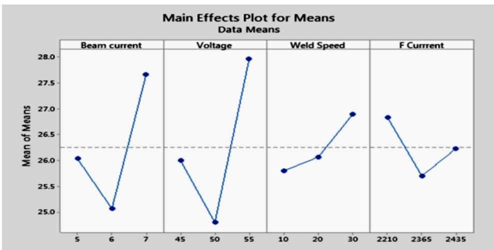

Figure 6. Analyzed Graph of Hardness HRC

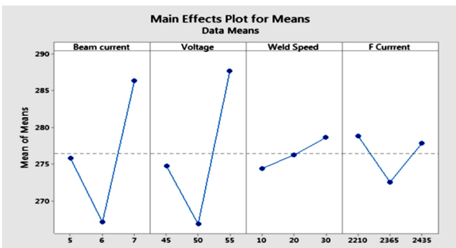

Figure 7. Analyzed Graph of Micro Hardness (HV)

max hardness and 50 KV will generate minimum hardness. If weld speed is considered only as an affecting factor, then welding at 30 mm/min will generate max hardness and 10 mm/min will generate minimum hardness. If Focus Current is considered only as an affecting factor, then welding at 2210 mA will generate max hardness and 2365 mA will generate minimum hardness. If all four factors are considered then microhardness will be maximum at Voltage 55 KV, Beam Current 7 mA weld speed 30 mm/min & focusing current 2210 mA. It has been found that all the results of hardness in HV and HRC were in a similar pattern and yield at similar points. Similar to hardness analysis, tensile strength analysis was also conducted and plotted for optimal results.

Taguchi design analysis of all four factors over Tensile strength can be easily understood with the analyzed graph of tensile strength presented in Figure 8 and it can be concluded as: If Beam Current is considered only as an affecting factor then welding at 7 mA will generate max Tensile strength and 5 mA will generate minimum Tensile strength. If Voltage is considered only as an affecting factor, then welding at 55 KV will generate max Tensile strength, and 45 KV will generate minimum Tensile strength. If weld speed is considered only as an affecting factor, then welding at 20 mm/min will generate max Tensile strength, and 30 mm/min will generate minimum Tensile strength. If Focus current is considered only as an affecting factor then welding at 2365 mA will generate max Tensile strength and 2435 mA will generate minimum Tensile strength. If all 4 factors are considered then Tensile strength will be maximum at Voltage 55 KV, Beam Current 7 mA weld speed 20 mm/min & focusing current 2365 mA.

3. 4. 3D Responses of Factors Affecting Tensile Strength and Hardness

The surface plot of Tensile Strength and Micro hardness with the combination of two factors are plotted and shown.

The 3D Surface Plot has been presented in Figure 9 to examine the relationship between tensile strength and two predictor variables (voltage and beam current), by viewing a three-dimensional surface of the predicted response optimum value of tensile strength can be selected. Figure 10 shows the surface plot of variation in tensile strength with two predictor variables (weld speed and beam current). Figure 11 shows the surface plot of variation in microhardness (HV) with two predictor variables (weld speed and beam current). Figure 12 shows the surface plot of variation in microhardness (HV) with two predictor variables (voltage and beam current).

Figures 13 to 15 show the contour plot of variation in tensile strength and microhardness (HV) with two predictor variables (weld speed and beam current and voltage and beam current). The optimal value of tensile strength and microhardness obtained through the surface plot and contour plot are approximately the same as it was calculated through the analyzed graph of tensile strength and microhardness.

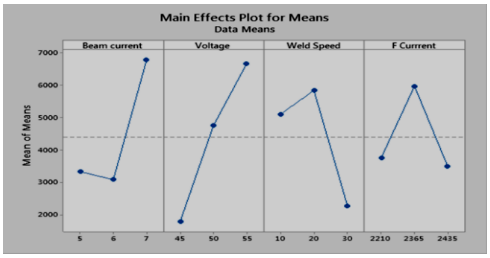

Figure 8. Analyzed graph of Tensile strength

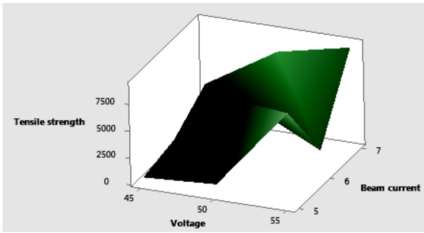

Figure 9. Surface Plot of Tensile strength vs. Beam current & Voltage

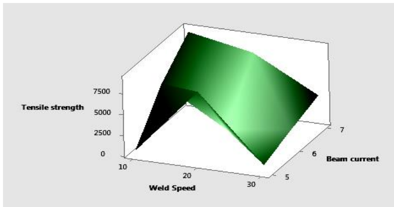

Figure 10. Surface Plot of Tensile strength vs. Beam current & weld Speed

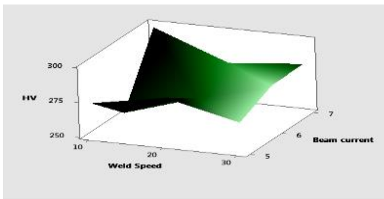

Figure 11. Surface Plot of HV vs. Beam current & weld Speed

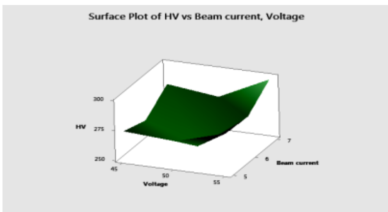

Figure 12. Surface Plot of HV vs. Beam current & Voltage

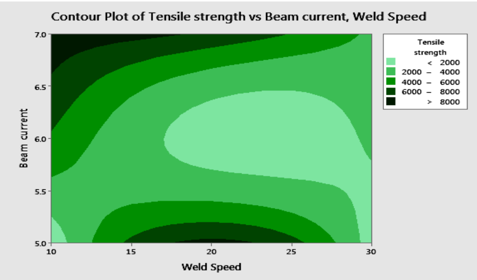

Figure 13. Contour Plot of Tensile Strength vs. Beam current & Weld speed

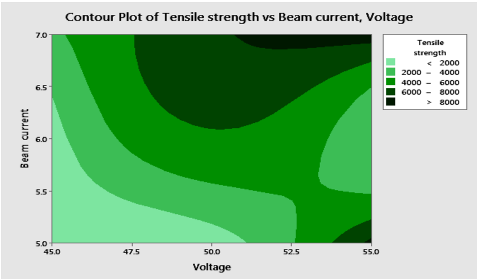

Figure 14. Contour Plot of Tensile Strength vs. Beam current & Voltage

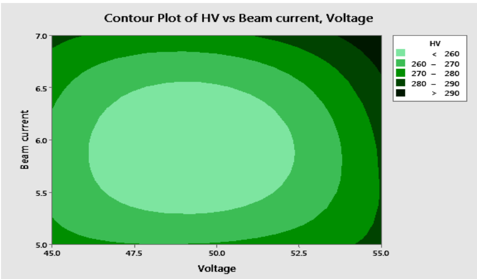

Figure 15. Contour Plot of HV vs. Beam current & Voltage

4. CONCLUSION

The study of relations between electron beam welding parameters and strength and hardness of welded joint and optimized strength and hardness by analyzing the value of these affecting parameters. After analysis, following conclusion has been made: (i) The optimized results for the tensile test were at a beam current of 7mA, voltage 55KV, welding speed 20mm/min, and focusing current at 2365mA. It has been found that the maximum tensile would yield at these parameters.

(ii) The value of maximum hardness appears at a beam current of 7 mA, and voltage 55 KV, welding speed of 30 mm/min, and focusing current at 2365 mA.

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Persian Abstract

چکیده

جوشکاری پرتو الکترونی برای جوشکاری قطعات کاربردهای قابل توجهی در صنعت فضایی نشان داده است. این کار در محیط خلاء انجام می‌شود تا مواد خارجی مانند هیدروژن، اکسیژن و سایر گازها وارد محیط کار نشوند. اتصال مواد مشابه و متفاوت با نسبت عمق به عرض بالا است و همچنین تمرکز در نقطه‌ای که قرار است قطعات جوش داده شوند، مهم‌ترین مزیت‌های این روش هستند. جوشکاری پرتو الکترونی باعث کاهش HAZ (منطقه تحت متأثر از گرما) می‌شود و آن را به یکی از مقبول‌ترین فرایندهای جوشکاری تبدیل می‌کند. در این مطالعه، ارزیابی اثر پارامترها بر سختی و استحکام مکانیکی با استفاده از نرم افزار Minitab انجام شده است. استحکام جوش پرتو الکترونی با تغییر پارامترهای جوشکاری تغییر می‌کند. بنابراین، با انتخاب پارامتر صحیح و بهینه می‌توان به بالاترین مقاومت جوش دست یافت. برخی از پارامترهای جوش به طور مستقیم بر استحکام جوش تأثیر می گذارند: آنهایی که برای آزمایشهای ما با وسواس انتخاب شدند. بنابراین، آرایه های ٤x٣برای بررسی ریزسختی و استحکام کششی نهایی آلیاژ $Fe_{49}Co_2V$ انتخاب شدند. سه سطح و چهار عامل برای تحلیل انتخاب شده‌اند. پارامترهای ورودی به عنوان شتاب دهنده‌ی ولتاژ (KV) ، سرعت جوش (میلی‌متر در دقیقه)، جریان پرتو (mA) و تمرکز جریان (mA) انتخاب می‌شوند. در این مطالعه بیشینه‌ی استحکام جوش در ولتاژ بالا (۵۵ کیلو ولت)، جریان پرتوی بالا (۷ میلی آمپر)، سرعت متوسط (۲۰ میلی‌متر در دقیقه) و تمرکز جریان متوسط (۲۳٦۵ میلی‌آمپر) به دست آمد. به طور مشابه، میکرو سختی به دست آمده در ولتاژ بالا (۵۵ کیلو ولت)، جریان پرتو زیاد (۷ میلی آمپر) و سرعت جوش بالا (۳۰ میلی متر در دقیقه) و حداقل تمرکز جریان (۲۲۱۰ میلی آمپر) حاصل شده است.