EXPERIMENTAL INVESTIGATION AND OPTIMIZATION OF RESISTANCE WELDING OF HETEROGENEOUS LDPE-HDPE COMPOSITE LAMINATES

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ABSTRACT

Resistance welding is widely used in manufacturing due to its efficiency in joining similar and dissimilar materials. This study investigates the resistance welding of low-density polyethylene (LDPE) and high-density polyethylene (HDPE) composites using stainless steel mesh as a heating element. The effects of welding parameters—current, pressure, and time—on lap shear strength and heat generation are analyzed using Taguchi's orthogonal array and ANOVA. Multi-response optimization is performed using the technique for order preference by similarity to ideal solution (TOPSIS). Microstructural analysis reveals interfacial and interlaminar failure modes, with higher heat input enhancing weld strength. Results indicate that increasing current and welding time improves both responses, while welding pressure has a varying influence. TOPSIS optimization identifies an optimal parameter combination maximizing lap shear strength and heat generation.

KEYWORDS

Resistance welding, Optimization, Multi-criteria decision making, TOPSIS

1 INTRODUCTION

Composite materials are extensively employed in a variety of engineering applications, such as automobiles, aerospace, structural components etc. These materials possess significant advantages with respect to excellent environmental resistance and greater dimensional tolerance [Totla 2023]. Joining these materials is traditionally carried out by adhesive bonding and mechanical fastening. However, other methods for composites, analogous to the conventional welding techniques for metals, are also explored. Methods akin to fusion welding, where the material is heated until it reaches a molten state, and techniques like solid-state welding that join materials below their melting point are also employed in composite welding. While these methods have been widely used, each has its limitations. Adhesive bonding, though effective, often suffers from poor thermal and environmental resistance, while mechanical fastening introduces stress concentrations and adds extra weight to the structure. Fusion-based methods, such as ultrasonic and laser welding, require precise process control to prevent thermal degradation, and friction stir welding can lead to excessive material flow and tool wear. Welding of composite materials is a complex process involving numerous parameters influencing the final weld characteristics.

Typically, welding of these materials requires heating them above the glass transition temperature (for amorphous polymers) and melting temperature (for semi-crystalline polymers), followed by allowing the weld interface to cool while maintaining constant pressure [Yousefpour 2004]. Various welding techniques are available, such as friction, electromagnetic and thermal welding [Zhao 2023, Wolf 2022]. Among all the welding practices, resistance welding is widely used, due to its cost effectiveness, simplicity and provision of good bond strength. In resistance welding, the samples are melted above the polymer glass transition temperature and with the application of force, the materials are subsequently joined. Resistance welding has shown better bond strength with respect to overall cost while joining the materials [Wei 2022]. Compared to other techniques, resistance welding ensures uniform heating, minimal material degradation, and better repeatability, making it particularly suitable for composite materials.

Heating element plays an important role during the resistance welding process as it provides the required heat for welding the two specimens [Marti 2023]. Previously, carbon fiber heating elements were used for joining the polymers. The main drawback of using carbon fiber was non-uniform heating due to low thermal conductivity and brittleness which may reduce the supply connectivity from the power supply. The problem associated with resistance welding using carbon fiber is related to the clamping pressure, which may cause damage to the fibers [Dube 2012, Warren 2016]. All these problems associated with carbon fiber can be effectively resolved with the use of stainless steel as the heating element. Utilization of a stainless-steel mesh heating element across the welding zone results in enhanced temperature uniformity and increased resistance to the pressure exerted by the connectors, which may lead to superior weld quality, mechanical performance, a longer processing period, better process control and higher repeatability [Shi 2007]. It was reported that in resistance welding, the time and temperature vary with wire mesh size [Dube 2012]. The past researchers also observed that bond strength of the weld would depend on the number of openings per linear inch of the wire mesh [Dube 2012]. Dube et al. [Dube 2007] performed resistance welding of thermoplastic composite skin/stringer joints and observed that use of stainless-steel mesh could provide better weld quality. Talbot et al. [Talbot 2013] employed transient heat transfer finite element models to optimize resistance welding parameters for thermoplastic APC-2/AS4 composites, utilizing a stainless-steel resistive wire mesh. It was concluded that the distance between electrode clamp and welding zone would play a crucial role in achieving better weld quality.

Due to the large number of input parameters involved in the welding process and their associated nonlinearity, it is not possible to achieve the optimized values of the responses under consideration just by trial-and-error method or based on the recommendations of the manufacturers/data handbooks. To resolve this issue, the earlier researchers often endeavored to optimize weld characteristics (responses) using various statistical tools, like Taguchi methodology, regression analysis etc. Eslami et al. [Eslami 2018] carried out friction stir welding to join polypropylene and polyethylene plates and adopted Taguchi methodology to optimize surface quality and strength of the weld. Singh et al. [Singh 2010] also employed Taguchi's L9 orthogonal array to investigate and optimize strength, hardness and porosity of the joint during friction welding of various types of plastics. Rotational speed, feed rate and welding time were treated as the welding parameters. Based on Taguchi methodology, Rezgui et al. [Rezgui 2010] determined the optimal combination of rotational speed, welding speed, pin diameter and hold time while joining high-density polymers using friction stir welding process. The derived results were later validated using finite element analysis. Ahmadi et al. [Ahmadi 2014] noticed that lap shear strength of dissimilar polymer friction welded joints could be significantly improved while identifying an appropriate combination of welding speed, rotational speed and tilt angle.

It can be unveiled from the above discussions that optimization of the welding parameters can significantly improve the welding properties. However, it has also been noticed that past researchers have primarily restricted themselves to single-objective optimization of different types of the welding processes, i.e. they have attempted to improve only a particular weld quality (response) without considering the other responses. Thus, in this paper, an attempt is put forward to simultaneously optimize both lap shear strength and heat generated during resistance welding of two heterogeneous composite materials, i.e. low-density polyethylene (LDPE) and high-density polyethylene (HDPE). For this purpose, a multi-criteria decision making (MCDM) tool in the form of technique for order preference by similarity to ideal solution (TOPSIS) is employed. Additionally, single-objective optimization is also performed by using Taguchi methodology.

Despite various research studies on resistance welding of composite materials, there is a lack of comprehensive analysis that simultaneously optimize both lap shear strength and heat generated, particularly in case of LDPE-HDPE composites. Majority of the existing research works primarily focus on single-objective optimization approaches, which may not address the complex interactions between multiple responses during resistance welding process. This paper addresses the identified research gap while employing TOPSIS to optimize both lap shear strength and heat generated during resistance welding of LDPE-HDPE composites. Additionally, it would contribute to the understanding of the effect of stainless-steel wire mesh as a heating element on weld quality and mechanical performance of the fused materials. By identifying the optimal welding parameters through a multi-objective optimization approach, this paper would offer valuable insights for improving the resistance welding process and quality of the resulting joints in composite materials.

The paper is organized as follows: Section 1 introduces the research topic. Section 2 describes the materials and methods employed during experiments. Results and discussion are presented in Section 3 along with microstructural analysis, lap shear strength, thermal behavior and optimized welding parameters. Section 4 concludes the paper while summarizing the main findings of the study.

2 MATERIALS AND METHOD

2.1 Experimental details

In this paper, effects of various input parameters, like current, welding pressure and welding time on resistance welding of LDPE and HDPE are investigated and statistically evaluated. Figure 1 exhibits the schematic representation of the resistance welding set-up.

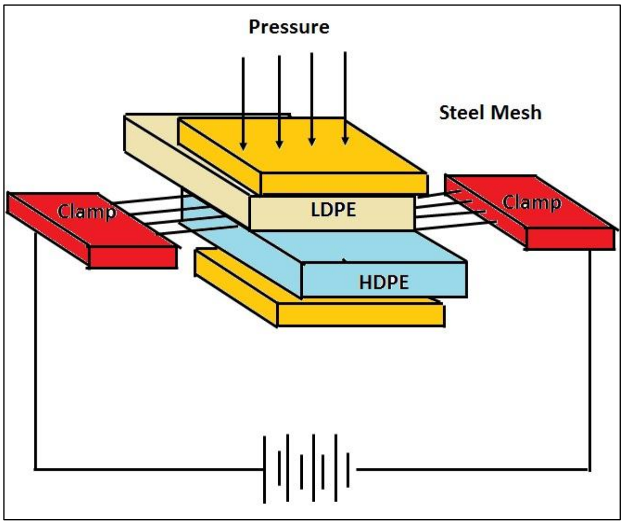


Figure 1. Schematic diagram of the welding setup

Initially, LDPE and HDPE samples have been fabricated using injection molding in the form of strips having dimensions 200 mm×20 mm×3 mm. Those strips have then been welded together using resistance welding having a steel mesh (0.06 mm) placed perpendicular between them. The steel mesh (heating element) has been clamped (made of copper) through which direct current (DC) power has been supplied at a constant load over the strips. During resistance welding of LDPE-HDPE composites, the operating levels of different input parameters, like current, welding pressure and welding time have been varied to study their effects on metallurgical, mechanical and thermal properties of the weld joints. Figure 2 shows photographs of various resistance welded joints at different combinations of the input parameters. An optical microscope (Zeiss Axiolab) has been employed to examine the microstructure of the welded specimens after tensile test. For thermal analysis, a thermocouple was attached to the composites and temperature data was recorded at different time durations (10, 15, 20 sec) while keeping the heat input same. As mentioned earlier, nine resistance welding experiments on LDPE-HDPE composites have been carried out based on Taguchi's L9 orthogonal array while varying each of the input parameters (i.e. current, welding pressure and welding time) at three different levels. The quality of the welds has been subsequently evaluated with respect to lap shear strength and heat generated. The process parameters are then optimized from both single and multi-objective viewpoint. Single-objective optimization of the resistance welding process is first performed employing Taguchi methodology, whereas TOPSIS is considered for multi-objective optimization of the said process. The welding parameters along with their levels are provided in Table 1. Table 2 provides the measured values of lap shear strength and heat input of various samples at different combinations of the welding parameters. The methodology deployed for optimization of resistance welding of LDPE-HDPE composites is portrayed in Figure 3.

Figure 2. Various resistance welded joints at different experiment trials

Welding parameter	Level		
	1	2	3
Current, I (A)	20	25	30
Time, T (s)	10	15	20
Pressure, P (MPa)	30	40	50

Table 1. Welding parameters and their levels

Exp. No.	I (A)	T (sec)	P (MPa)	Lap shear strength (MPa)	Heat input (Joule)
1	20	10	30	1.667±0.119	412±12.33
2	20	15	40	2.234±0.157	618±13.46
3	20	20	50	3.791±0.086	824±8.99
4	25	10	40	2.184±0.054	643±26.17
5	25	15	50	5.93±0.181	965±9.78
6	25	20	30	7.406±0.529	1287±27.23
7	30	10	50	4.392±0.19	927±32.37
8	30	15	30	5.449±0.47	1390±47.29
9	30	20	40	7.895±0.51	1854±64.25

Table 2. Experimental data

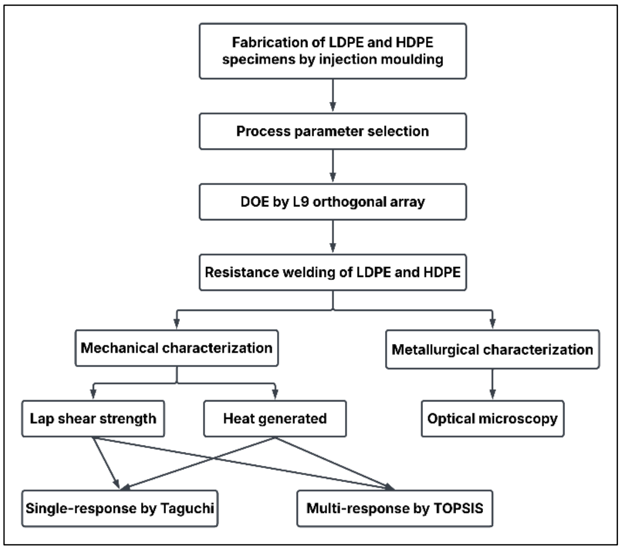


Figure 3. Flowchart of the optimization procedure

2.2 *TOPSIS*

The technique for order preference by similarity to ideal solution (TOPSIS) is one of the well-established and reliable multi-criteria decision-making (MCDM) tools employed for solving complex decision-making problems in diverse domains of engineering and management operations [Hwang 1981]. TOPSIS is based on the principle that the best alternative should have the shortest Euclidean distance from the ideal best solution and the farthest distance from the ideal worst solution. It systematically ranks different alternatives by calculating a closeness coefficient, which determines the relative performance of each alternative.

In this study, TOPSIS is used to optimize the resistance welding process by simultaneously considering lap shear strength and heat generated as decision criteria. Unlike traditional single-objective optimization techniques that focus on improving only one response at a time, TOPSIS provides a balanced solution by ranking parameter combinations that maximize weld strength while ensuring sufficient heat generation. This method is particularly advantageous for multi-objective problems where responses may have conflicting requirements.

The procedural steps involved in TOPSIS are presented below:

Step 1: Develop decision matrix (D) and weight vector (W)

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

$$W = [w_1 \quad \dots \quad w_n] \quad (2)$$

Step 2: Construct the normalized decision matrix (N)

$$N = \begin{bmatrix} n_{11} & n_{12} & \cdots & n_{1n} \\ n_{21} & n_{22} & \cdots & n_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ n_{m1} & n_{m2} & \cdots & n_{mn} \end{bmatrix}, \text{ where } n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

Step 3: Formulate the weighted normalized decision matrix (N^w)

$$N_{ij}{}^{w} = w_j \times n_{ij}\,,\ i \in [1,m]\ ;\ j \in [1,n] \quad (4)$$

Step 4: Estimate the ideal positive (A_j^+) and ideal negative (A_j^-) solutions

$$A_j^+ = \begin{cases} \max\ N_{ij} \mid j\ \in B \\ \min\ N_{ij} \mid j\ \in\ C \end{cases} \quad (5)$$

$$A_j^- = \begin{cases} \min\ N_{ij} \mid j\ \in B \\ \max\ N_{ij} \mid j\ \in\ C \end{cases} \quad (6)$$

where B is the set of benefit criteria (requiring higher values), and C is the set of cost criteria preferred with lower value)

Step 5: Determine the separation measures (S_i^+ and S_i^-)

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (N_{ij} - A_j^+)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (N_{ij} - A_j^-)^2} \quad (8)$$

Step 6: Compute the closeness coefficient (CC_i)

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-}\,, \text{ where } 0 \le CC_i \le 1,\ i \in [1,m] \quad (9)$$

3 RESULTS AND DISCUSSION

3.1 *Microstructural examination*

Figure 4 shows the optical micrographs of the specimens after lap shear failure of the welded joints. It can be observed that with lower heat input, the extent of melting at the interface is limited, reducing the interaction between the laminates (LDPE and HDPE) and the mesh. However, with increase in heat input, melting of the laminates as well as mesh takes place, as noticed in Figure 4. It would result in better bond strength and widening of the mesh surface. It has been reported that failure of the laminates at low heat input is interfacial, whereas, at higher heat input, it is interlaminar [Brassard 2021]. Interfacial failure occurs when the laminates and mesh observe a cohesive bond or discontinuity of the laminates without damaging the wire mesh. On the other hand, interlaminar failure is due to failure of the laminate or failure of the heating element (mesh), or when both fail together [Shi 2007]. Figure 5 shows various failures occurred during resistance welding of LDPE-HDPE composites.

The microstructural analysis revealed that at lower heat input, interfacial failure dominated due to inadequate melting between LDPE and HDPE layers. As the heat input increased, interlaminar failure was observed, resulting in better bonding between the laminates and mesh. However, achieving uniform temperature distribution across the joint remains a challenge, especially at the overlap edges, where localized temperature variations can lead to weak bonding. This issue has been widely reported in resistance welding studies, where maintaining consistent temperature is crucial to prevent defects [Ma 2024]. Optimizing heat input distribution could further improve joint integrity.

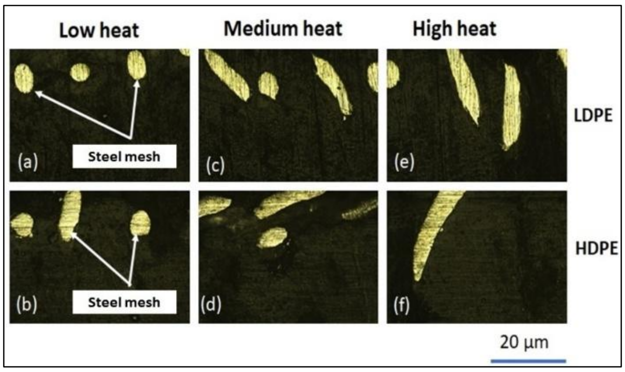


Figure 4. Optical micrographs of the resistance weld joint

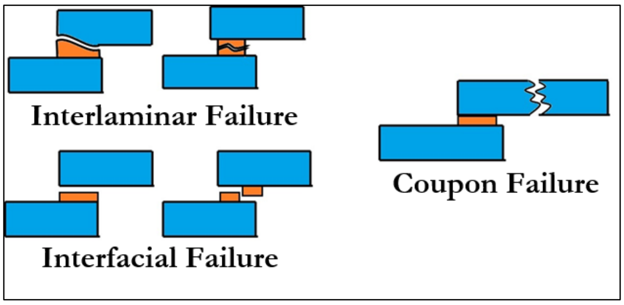


Figure 5. Different failures during resistance welding

3.2 *Lap shear strength*

Figure 6 shows a comparative analysis between lap shear strength and heat input. The results confirm a direct relationship, where higher heat input improves lap shear strength by enhancing melting and bonding at the interface. Conversely, lower heat input leads to interfacial failure due to incomplete fusion of the laminates. Though the stainless-steel mesh ensures heating uniformity, additional factors such as wire diameter can influence lap shear strength, as larger diameters may reduce weld strength. However, since the present study employed a constant wire diameter, failure modes were primarily interfacial at low heat input and interlaminar at high heat input [Dube 2012].

The results show that lap shear strength increases with heat input, reinforcing the importance of proper melting and bonding at the interface. While stainless steel mesh improves heating uniformity, further modifications to the heating element could enhance performance. Recent studies have suggested that treating heating elements with surface agents like silane can significantly improve interfacial adhesion by promoting better resin infiltration, thereby increasing lap shear strength [Long 2024].

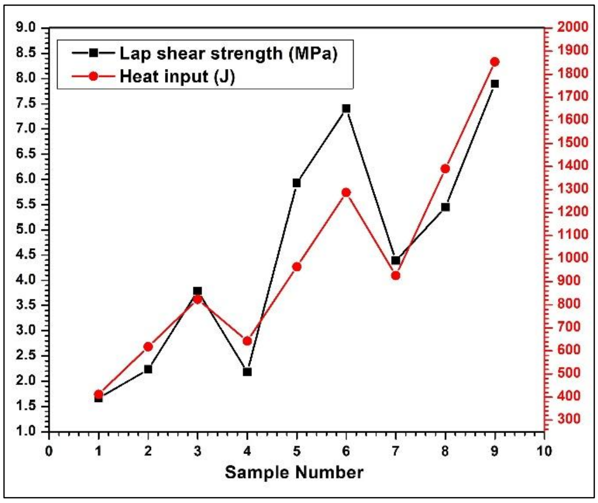


Figure 6. Relationship between lap shear strength and heat input

3.3 *Thermal behaviour*

Figure 7 vividly illustrates the thermal behaviour of LDPE-HDPE composite laminates under varied welding times. It provides a comprehensive analysis of temperature changes throughout different intervals of the welding process, specifically at 10 seconds, 15 seconds, and 20 seconds. At the outset of each welding process, a minimal temperature difference between each period is observed. For instance, at the start of welding (t = 0s), the temperatures are 32.9°C, 31.7°C, and 31.9°C for the 10-, 15-, and 20-seconds welding time, respectively. This negligible divergence demonstrates the uniformity in initial conditions.

As the welding time extends, there is a noticeable elevation in temperature. The 10-second welding session peaks at 148.2°C (t = 8s), after which the temperature drops gradually. For the 15-second welding session, a steeper thermal rise is observed, attaining a maximum of 247.3°C (t = 12s), while the 20-second welding session hits a zenith at 315.9°C (t = 15s). These ascending thermal profiles suggest that the duration of welding time significantly contributes to a higher thermal input, confirming the positive correlation between heat input and weld time.

Contrarily, a more extended welding duration does not simply culminate in an augmented temperature. The cooling process also stretches. The 10-second welding session time cools down to room temperature by t = 30s, while the 15-second and 20-second welding session require approximately 40 seconds and 42 seconds, respectively. Thus, it can be inferred that the cooling time is extended with longer weld times. Moreover, the temperature-time graph for each welding period displays a shifting trend towards the right, suggesting an extension in the time required to reach peak temperature and subsequently cool down. This rightward shift could be the resultant of consistent voltage and current applied for different welding periods, leading to a variable microstructure of the weld, which is primarily determined by the thermal history experienced by the material during the welding process.

The recorded thermal profiles demonstrate that as welding time increases, the peak temperature rises, which influences material bonding and mechanical strength. However, nonuniform heating remains a concern, particularly at the laminate edges. Innovative approaches, such as integrating ultrasonic methods, have been explored to improve temperature distribution and resin flow, leading to better joint integrity [Ma, 2024]. Such methods could complement resistance welding by reducing thermal gradients and ensuring consistent fusion across the joint.

3.4 Optimization process

During optimizing the resistance welding process of LDPE-HDPE composites, based on Taguchi's L9 orthogonal array, effects of current, welding pressure and welding time on lap shear strength and heat generated is first parametrically studied. Multi-objective optimization of the process is later conducted to simultaneously maximize lap shear strength and heat generated. Figure 8 shows the schematic representation of the optimization process.

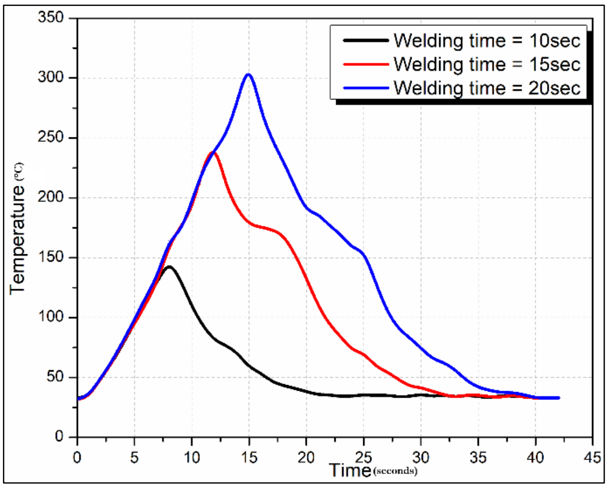


Figure 7. Thermal profiles at varying weld times

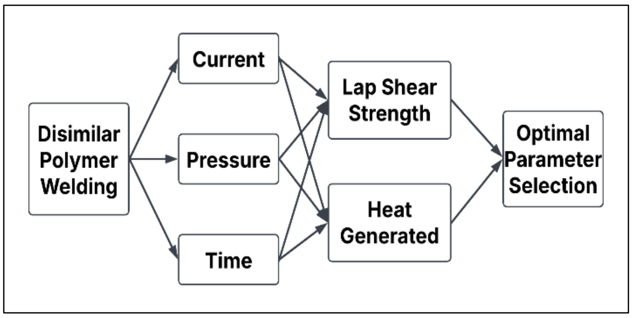


Figure 8. Schematic representation of the optimization process

3.4.1 Effect of welding parameters on lap shear strength

Parametric investigation of the welding process parameters reveals that with increasing values of current, lap shear strength also increases, as depicted in Figure 9. However, it is noticed that initially, lap shear strength is monotonically increasing with increase in current, but after mid-level of current, its improvement is less sharp. Similarly, as expected, higher is the welding time; better is the lap shear strength of the dissimilar polymeric weld. On the other hand, welding pressure has a more complex relationship with lap shear strength which initially decreases with increase in the welding pressure but then starts rising beyond the mid-level of welding pressure. To further understand the importance and impact of each of the welding parameters on lap shear strength of dissimilar polymeric welds, analysis of variance (ANOVA) is conducted assuming a first-order linear model. It can be observed from Table 3 that the linear model has a R^2 value of 93%, indicating that it can be able to describe 93% of the variations in the observations. Based on ANOVA results, the approximate impact of each of the welding parameters on lap shear strength is estimated. It can be noticed from Figure 10 that current and welding time are the significant parameters influencing lap shear strength. To further investigate which parameters is most significant for single-objective optimization of lap shear strength, an aggregated signal-to-ratio (S/N ratio)-based ranking of the welding parameters is conducted, as shown in Table 4. Thus, from the comprehensive analysis of ANOVA and aggregated S/N ratio, it can be concluded that welding time is the most important parameter, followed by current and welding pressure. It can also be validated with respect to maximum steepness of welding time in Figure 9. Thus, for achieving maximum lap shear strength of dissimilar polymeric welds, higher operating levels of all the considered welding parameters (current, welding time and welding pressure) are recommended.

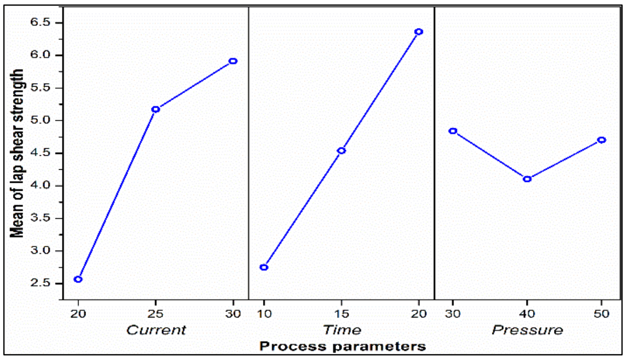


Figure 9. Main effect plot of welding parameters on lap shear strength

Source	DF	Adj. SS	*F*-Value	*p*-Value
Current	2	18.5634	6.56	0.132
Time	2	19.6175	6.93	0.126
Pressure	2	0.9208	0.33	0.755
Error	2	2.8313		
Total	8	41.9329		
R^2	93.25%			

Table 3. ANOVA results for lap shear strength

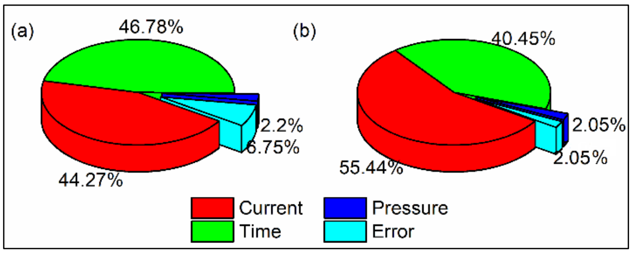


Figure 10. Contribution of welding parameters on (a) lap shear strength (b) heat generated.

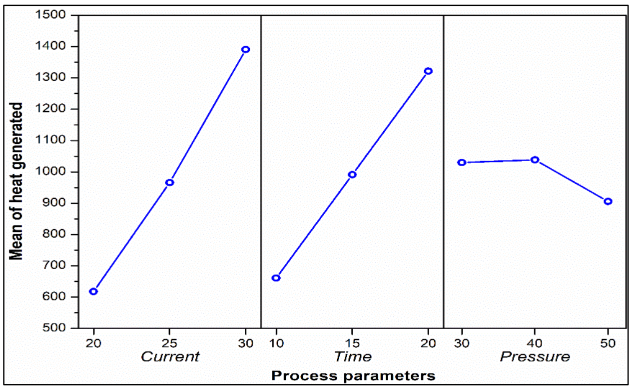
Welding parameter	Level 1	Level 2	Level 3	Delta	Rank
Current	2.564	5.173	5.912	3.348	2
Time	2.748	4.538	6.364	3.616	1
Pressure	4.841	4.104	4.704	0.736	3

Table 4. Aggregated S/N ratio-based ranking of welding parameters on lap shear strength

3.4.2 Effect of welding parameters on heat generated

From Figure 11, it can be observed that heat generated in the weld zone increases monotonically with increasing values of both welding current and welding time. However, increase in welding pressure seems to have a small detrimental impact on the heat generated. The corresponding ANOVA results are exhibited in Table 5, showing that the linear model has a remarkably high R^2 value of 98%. Figure 10 depicts that weld current and welding time have 55% and 40% impacts on the linear model of heat generated indicating that weld current is the most important parameter significantly influencing the heat generated during the resistance welding process. The aggregated S/N ratio-based analysis, as provided in Table, 6 too indicates that welding current, followed by welding time are the most parameters for quantifying the heat generated at the weld. Based on Figure 11 and Table 6, higher values of current and welding time, and moderate value of welding pressure would lead to maximum amount of heat generated during resistance welding of dissimilar polymeric joints.

Figure 11. Main effect plot of the welding parameters on heat generated.



Source	DF	Adj. SS	*F*-Value	*p*-Value
Current	2	898118	27	0.036
Time	2	655216	19.7	0.048
Pressure	2	33264	1	0.5
Error	2	33264		
Total	8	1619862		
R^2	97.95%			

Table 5. ANOVA results of heat generated.

Process Parameter	Level			Delta	
	1	2	3		
Current	55.479	59.355	62.522	7.044	1
Time	55.938	59.460	61.959	6.021	2
Pressure	59.119	59.119	59.119	0.000	3

Table 6. Aggregated S/N ratio-based ranking of welding parameters for heat generated.

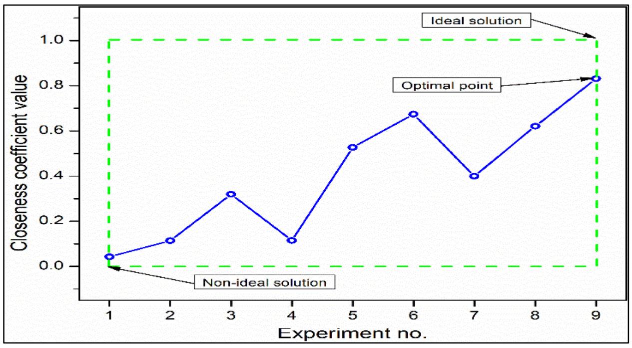


Figure 12. Closeness coefficients of the welding experiments

3.4.3 Optimal parameter selection using TOPSIS

The search for selection of the optimal combination of welding parameters from single-objective viewpoint reveals that there are some conflicts in the relative importance of the parameters considered and with respect to optimal parametric settings. Although higher values of both current and welding time are recommended for having maximum values of lap shear strength and heat generated, there is a difference in respect of welding pressure. For higher lap shear strength, higher welding pressure is required, whereas its moderate value is desired for maximum heat generated. As setting of two completely different parametric intermixes during a single welding operation is infeasible, it becomes extremely ardent to conduct multi-objective optimization of the said process using TOPSIS aiming in identification of a unique combination of welding parameters for simultaneous maximization of both the responses under consideration. Based on the procedural steps adopted for TOPSIS, the experimental data of Table 2 (original decision matrix) is first vector normalized, as provided in Table 7. On the other hand, the relative importance (weight) of lap shear strength and heat generated is computed using standard deviation method as 0.58 and 0.42, respectively. The weighted normalized decision matrix, derived after multiplying elements of the normalized decision matrix by the corresponding criteria weights, is presented in Table 7. Based on the calculated values of closeness coefficient, it can be noticed that experiment trial number 9 provides the optimal combination of the considered welding parameters for achieving maximum values of both the responses. Figure 12 also confirms the superiority of trial number 9 over the remaining experiments in simultaneously maximizing lap shear strength and heat generated. Figure 13 shows that higher weld current and welding time accompanied by lower welding pressure (A3B3C1) are most suitable to weld dissimilar polymeric composites.

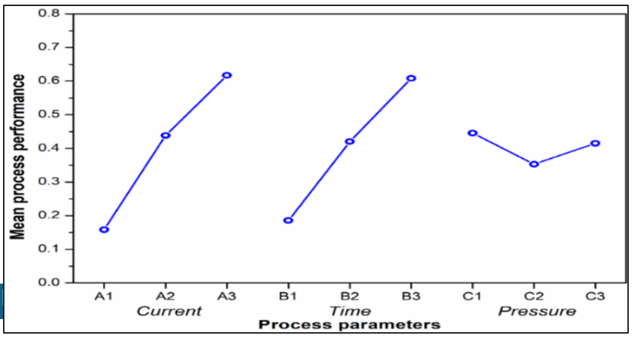


Figure 13. Optimal settings of the welding parameters

Exp. No.	Separation measures		CC_i	Rank
	S_i^+	S_i^-		
1	0.3037	0.0135	0.0425	9
2	0.2709	0.0348	0.1138	8
3	0.2136	0.1002	0.3193	6
4	0.2696	0.0349	0.1146	7
5	0.1647	0.1832	0.5266	4
6	0.1216	0.2514	0.6740	2
7	0.1903	0.1268	0.3999	5
8	0.1181	0.1933	0.6207	3
9	0.0620	0.3046	0.8308	1

Table 7. Closeness coefficients and rankings using TOPSIS

The optimized parameters obtained from TOPSIS confirm that higher current and welding time enhance both lap shear strength and heat generation, while moderate welding pressure is preferred for balanced performance. Resistance welding offers significant advantages over other composite welding techniques, particularly in terms of energy efficiency and automation compatibility, as it consumes less power than other methods and can be seamlessly integrated into automated systems, reducing production costs by up to 40% [Stankiewicz 2024]. These factors make resistance welding a viable solution for large-scale industrial applications.

4 CONCLUSIONS

This study investigates the resistance welding of dissimilar LDPE-HDPE composite laminates using stainless steel mesh as a heating element. The experimental findings highlight the influence of welding parameters—current, pressure, and time—on lap shear strength and heat generation. Microstructural analysis reveals that lower heat input leads to interfacial failure, while higher heat input results in interlaminar failure, improving weld quality. Optimization using Taguchi methodology and TOPSIS confirms that increased welding current and time enhance both strength and heat generation, with optimal parameter settings identified through multi-objective decision-making.

Despite these findings, the study is limited to LDPE-HDPE composites and a single heating element type. Future research could explore different polymer composites, alternative heating elements (e.g., carbon nanotube films), and hybrid welding techniques. Additionally, incorporating machine learning models for predictive optimization and analyzing long-term weld durability under varying environmental conditions would further advance the field. These directions will expand the applicability of resistance welding for composite materials in diverse industrial sectors.

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