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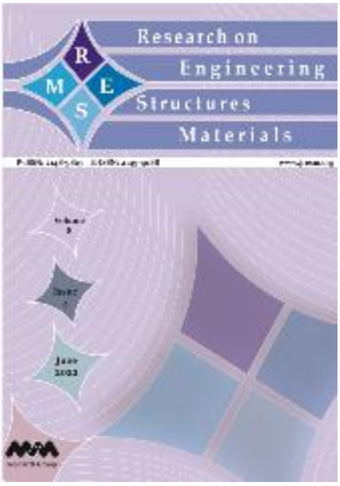

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Research Article

Process parameter improvement for NITi's electrical discharge machining (EDM) process utilizing the TOPSIS approach

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Abstract

The current work focuses on finding the ideal set of Electro Discharge Machine (EDM) process variables for machining Shape memory alloy (NiTi). NiTi alloy is a significant class of smart material with several unique properties. There are numerous uses for NiTi in the security, marine, biomedical, and aerospace industries. NiTi is particularly difficult to cut using conventional machining methods due to its hardness; nevertheless, the material can be removed using an electric discharge machining technique. The experiments were carried out using Taguchi's L27 orthogonal array. A Multi-criteria decision-making (MCDM) technique known as TOPSIS is used to optimize the response performance variables of material removal rate (MRR) and surface roughness (SR). TOPSIS combines multiple objectives into a single objective and provides the optimum set of parameters, From the optimization results, the optimal combination of process parameters is obtained at Voltage=30V, Discharge Current= 20A, Ton=35µs, Toff=8µs. Confirmatory experiments show a satisfactory improvement of preference values utilizing TOPSIS in the EDM experimental and initial settings of 1.82.

1. Introduction

According to the state of research, shape memory alloy (SMA) development is proceeding successfully. SMA demand is on the rise for a wide range of engineering components. When used as a binary alloy, nickel and titanium have different element weight percentages in the SMA [1]. Smart materials in the NiTi class have special qualities like super elasticity, high strength, biocompatibility, etc. In the fields of defense, aerospace, and medicine, NiTi alloy is widely applied. This alloy is difficult to machine using traditional machining techniques because it has unique qualities and applications. Instead, this alloy is machined using non-conventional techniques such as electric discharge machining (EDM) [2]. By generating controlled sparks between an electrode with a specific form and an electrically conductive workpiece, electrical discharge machining (EDM), a popular technique for shaping conductive materials, can be utilized to remove material [3]. Sushil Kumar Choudhary et al. examine the research that was done on die-sinking EDM, water-in EDM, dry EDM, and powdered mixed electric discharge machining from inspection through development. He noted that the main advancement in research had improved tool wear and metal removal rate [4]. Azizul Bin Mohamad et al., optimization of EDM parameters process and response parameters using Taguchi method. They observed that pulse on time and discharge current were most effective on the Surface and also duty factor as least influencing the machining process quality [5]. K.M Patel et al. investigated the effect of process parameters on surface quality. They investigated that the most significant factor is discharge current which affects surface quality. Surface roughness increases with an

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increase in discharge current and also affects the metal removal rate [6]. Singh Balbir et al. investigate the process of alloying AA 6061/ SiCp using Cu-W powder metallurgy electrodes in EDM. They investigated the effects of peak current, gap voltage, pulse off time, and pulse on time on response parameters metal removal rate, electrode wear, and surface roughness. They analyze that using powder metallurgy improves the surface quality [7].E. Aliakbari et al. found the ideal rotary process parameter setting and deduced from this experiment that the most influential input parameters on MRR, EWR, and SR are current, pulse on time, electrode rotational speed, and electrode shapes [8].Bala Murugan Gopalsamy et al, noticed that the parameters that have the most influence on rough machining are the cut width and depth. The most important factor in finish machining is cutting speed [9]. Ho and Newman presented a review of the electrical discharge machining process and discussed the parameters that are contributing to machining efficiency. EDM process involves many process parameters which can be broadly classified into two categories such as electrical and non-electrical process parameters. They stated that empirical modeling can be better described in the EDM process as it is stochastic in nature [10]. Mr. L.G. Machado et al. give a review on the medical applications of shape memory alloys. The aim of this review paper is to explain the most exciting uses of SMA in the biomedical field and to provide a brief overview of its thermomechanical behavior. These include surgical tools and uses for the heart and joints [11]. Multiple performance characteristic issues require the modeling and optimization of the EDM process. Kasdekar, D. K. et. al. suggested a TOPSIS, Simple Additive Weighting (SAW) method based on entropy to address the multi-performance parameter optimization issue in EDM [12]. Tripathy, S. et. al. assessed the efficiency of improving several performance variables for powder-mixed EDM of H-11 die steel using the copper electrode by combining the Taguchi technique with TOPSIS and grey relational analysis [13]. Vaddi, V. R. et. al. worked on using TOPSIS and the Taguchi technique to optimize EDM machining parameters for titanium alloys (Ti-6Al-4V), taking into account various performance concerns. All of the results demonstrated TOPSIS's ability to address a variety of concrete EDM-related challenges using the Taguchi approach. This technique reduced a multi-performance problem to a single equivalent objective problem [14]. Phan Huu Nguyen et. al. adjusts the process parameters for milling titanium alloy specimens with tungsten carbide. To determine improved process variables including voltage, capacitance, and electrode rotating speed, the Taguchi-TOPSIS approach was applied. To assess the depth of machining, overcut, and tool wear rate, voltage, capacitance, and electrode rotational speed were taken into account. The investigation revealed that the best settings can result in better surface polish and greater machining precision [15].M Somasundaram et. al. carries out studies to mill AZ31 alloy using EDM to optimize process parameters by combining multi-attribute optimization and Taguchi methodologies. In this work, multiple-response optimization was accomplished using Multi-Criteria Decision Making (MCDM) approaches such as the TOPSIS methodology and Grey Relational Analysis (GRA). Due of TOPSIS' flexibility in determining how much weight to give the response based on the need, researchers came to the conclusion that it is the best method for solving real-time multi-criteria problems. With GRA, which has a constant value for all response variables, it is not conceivable. [16].

The current study's objective is to maximize the material removal rate and minimize surface roughness during the machining of NiTi alloy by optimizing the electric discharge machining process parameter. Surface roughness (SR) and material removal rate (MRR) were the output parameters, and pulse current, voltage, gap, and pulse on-off time were the input parameters.

2. Design of Experiment

2.1 Experimental Setup

An EDM machine (Valpak) was used in this study to conduct experiments shown in Fig. 1. An electrode was a rectangular, pure copper plate that measured 40 mm by 40 mm by 20 mm. A moving dielectric fluid, kerosene, kept the workpiece and electrode apart. Shape memory alloy (NiTi) was used as the workpiece's material. For experimentation, shape memory alloy pates with dimensions of 25 mm by 40 mm by 15 mm were used. As a workpiece, NiTi shape memory alloy has been utilized in orthopedics to fix fractured bones.

Fig. 1 EDM setup and Machined plates (Ni-Ti Alloy)

Placing the electrode in the ram hold and fixing it in place. To maintain a very small gap of 50 µm between the electrode tip and the surface of the workpiece, its height was automatically adjusted by the machine with respect to the workpiece. keeping the workpiece in place on the machine's work table's magnetic chuck. Flushing the dielectric fluid up to the height where the electrode sparking region is totally submerged, flooding the volume (work tank) around the workpiece. Perform the machining operation for the specified amount of time. It is possible to see intermittent sparking through the dielectric fluid. Small craters are generated as a result of a high number of current discharges that all contribute to the removal of material from the workpiece. The workpiece is removed from the device and its surface roughness (SR) is checked with Taylor-Hobson Surf Com equipment. The readings are noted down.

2.2. Selection of an orthogonal array

Machining experiments for determining the optimal machining parameters were carried out by setting: For each experiment the combinations of the 4 input parameters viz. Gap Voltage(V) in the range of 25V to 100V, Discharge Current (A) in the range of 10A to 20A, Pulse on-time (Ton) in the range of 35 µs to 100 µs, pulse off-time (Toff) in the range of 5 µs to 39 µs, all having 3 levels (Table 1)

The total degree of freedom when there are three independent variables, each with three levels, is nine. As a result, the chosen orthogonal array must include at least 9 experiments. This condition is satisfied by an L_9 orthogonal. Three levels and four factors were chosen for this investigation. An orthogonal array L_{27} was chosen for this experiment [18].

Table 1. Initial EDM Parameter

EDM Parameters	Unit	Level-1	Level-2	Level-3
Gap Voltage	V	25	30	100
Discharge current	A	10	15	20
Pulse On Time	µs	35	50	100
Pulse Off Time	µs	5	8	9

2.3. Conducting the Experiment

After choosing the orthogonal array, the experiments are carried out using the level combinations. The execution of all the experiments is required. L_{27} orthogonal array was used since there were four components and three levels in this investigation [23].

Table 2. Orthogonal Array of Experimental Combination

Test	Gap Voltage	Discharge current	Pulse On Time	Pulse Off Time
1	25	10	35	5
2	25	10	35	8
3	25	10	35	9
4	30	15	50	5
5	30	15	50	8
6	30	15	50	9
7	100	20	100	5
8	100	20	100	8
9	100	20	100	9
10	25	15	100	5
11	25	15	100	8
12	25	15	100	9
13	30	20	35	5
14	30	20	35	8
15	30	20	35	9
16	100	10	50	5
17	100	10	50	8
18	100	10	50	9
19	25	20	50	5
20	25	20	50	8
21	25	20	50	9
22	30	10	100	5
23	30	10	100	8
24	30	10	100	9
25	100	15	35	5
26	100	15	35	8
27	100	15	35	9

2.4. Machining Performance Measure

Surface Roughness Measurement-

The parameter Ra, which is the most frequently used, was chosen for this study from a variety of surface finish characteristics, including roughness average (R_a), root-mean-square (rms) roughness (R_q), and maximum peak-to-valley roughness (R_y or R_{max}). The experiments were carried out with various Gap voltage, Discharge current, Pulse on-time, and Pulse on-time settings (Table 2). The Taylor-Hobson Surf Com equipment was used to measure the specimens' surface roughness.

Material Removal Measurement-

Machining was executed using a fixed time and the MRR was measured by determining the weight difference of the workpiece before and after machining. The MRR measured in cubic millimeters per minute, was obtained using Eq. (1).

$$MRR = \frac{(\mathrm{W}_1 - W_2)}{\rho_w\, t} * 10^3 \tag{1}$$

Where W_1 and W_2 are the work piece weight before and after machining, respectively, ρ_w is the density of the NiTi, SMA, and t is the machining time (min).

3. Result in Analysis

Minitab TM 18 tool is employed for data analysis. Two response parameters from the result in table 3 are selected for study in order to determine the best combination that can produce a high-quality machined surface finish. 27 experiments were carried out in accordance with the L_{27} orthogonal array, with the findings for surface roughness and metal removal rate displayed in table 3.

Table 3. Result Table

Test	Gap Voltage	Discharge current	Pulse On Time	Pulse Off Time	Surface roughness	MRR (mm^3/min)
1	25	10	35	5	5.31	7.375
2	25	10	35	8	5.35	6.146
3	25	10	35	9	5.55	6.914
4	30	15	50	5	6.25	6.062
5	30	15	50	8	6.15	6.056
6	30	15	50	9	6.44	6.062
7	100	20	100	5	6.01	6.062
8	100	20	100	8	5.9	7.375
9	100	20	100	9	6.26	7.375
10	25	15	100	5	6.52	6.291
11	25	15	100	8	6.32	5.531
12	25	15	100	9	6.82	4.425
13	30	20	35	5	4.62	7.375
14	30	20	35	8	4.52	8.749
15	30	20	35	9	5.12	7.375
16	100	10	50	5	5.01	7.375
17	100	10	50	8	5.24	7.375
18	100	10	50	9	5.44	6.914
19	25	20	50	5	6.11	6.062
20	25	20	50	8	5.96	7.375

21	25	20	50	9	5.34	6.146
22	30	10	100	5	5.12	6.062
23	30	10	100	8	5.05	7.375
24	30	10	100	9	5.37	5.531
25	100	15	35	5	5.2	7.375
26	100	15	35	8	5.18	7.375
27	100	15	35	9	5.34	7.375

4. Optimization Using Technique for Order of Preference (TOPSIS) & Results

A technique for multi-criteria decision analysis is called TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). By determining weights for each criterion, normalizing scores for each criterion, and calculating the geometric distance between each alternative and the ideal alternative, which is the alternative with the best score for each criterion, this compensatory aggregation method compares a set of alternatives. The criteria are assumed to be monotonically growing or decreasing by TOPSIS [14,15].

The steps involved in multi-objective optimization are [16]:

Step 1. Determine the objective and identify the pertinent evaluation criteria.

Step 2. Construct a decision matrix based on all the information available for the criteria. Each row of the decision matrix is allocated to one alternative and each column to one criterion. Therefore, an element, x_{ij} of the decision matrix shows the performance of ith alternative with respect to jth criterion.

Step 3. Obtain the normalized decision matrix, r_{ij} using the following equation:

$$r_{i_j} = \frac{x_{i_j}}{\sqrt{\sum_{i=1}^{m} x_{i\ j}^{2}}} \tag{2}$$

Step 4. Construct the weighted normalized decision matrix.

$$v_{i_j} = r_{i_j} \times w_j \tag{3}$$

Step 5. Determine the Positive ideal Row (IDR) that one with the largest observed value for each column.

$$\text{IDR} = (\max v_{i1}, \max v_{i2}, \ldots\ldots, \max v_{in}) = (v_1^+, v_2^+, \ldots\ldots, v_n^+) \tag{4}$$

Similarly, the Negative-ideal Row (NDR) that one with the smallest value for each column.

$$\text{NDR} = (\min v_{i1}, \min v_{i2}, \ldots\ldots, \min v_{in}) = (v_1^-, v_2^-, \ldots\ldots, v_n^-) \tag{5}$$

Step 6. Measure the distance, d_i^+ for i= 1,2, 3,……,m, of each alternative from the positive ideal one.

$$S_i + = [\textstyle\sum_{j=1}^{n} \left(v_{i_j} - v_j^+ \right)^2]^2 \qquad \text{for i= 1,2, 3,……,m.} \tag{6}$$

Similarly, Measure the distance, d_i^- for i= 1,2, 3,……,m, of each alternative from the negative ideal one.

$$S_i - = [\textstyle\sum_{j=1}^{n} \left(v_{i_j} - v_j^- \right)^2]^2 \qquad \text{for i= 1,2, 3,……,m.} \tag{7}$$

Step 7. Calculate the relative closeness of alternatives to ideal solution by computing what is known as Composite Index (CI).

$$P_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{8}$$

Step 8. A set of alternatives is arranged in descending order, according to P_i value, indicating the most preferred and the least preferred solutions.

The normalized decision matrix for the provided data is shown in Table 4. Table 6 illustrates the Weighted Decision matrix, respective Euclidian distances, degree of closeness, and ranks for a set of input parameters whereas Table 5 displays the weighting applied to each output response variable. These are all taken from an excel spreadsheet that was created.

Table 4. Normalized Decision Matrix

Experimental Result		Normalized Output	
Surface roughness	MRR (mm^3/min)	Surface roughness	MRR (mm^3/min)
5.31	7.375	0.1811	0.1376
5.35	6.146	0.1825	0.1147
5.55	6.914	0.1893	0.129
6.25	6.062	0.2132	0.1131
6.15	6.056	0.2098	0.113
6.44	6.062	0.2197	0.1131
6.01	6.062	0.205	0.1131
5.9	7.375	0.2012	0.1376
6.26	7.375	0.2135	0.1376
6.52	6.291	0.2224	0.1174
6.32	5.531	0.2156	0.1032
6.82	4.425	0.2326	0.0826
4.62	7.375	0.1576	0.1376
4.52	8.749	0.1542	0.1632
5.12	7.375	0.1746	0.1376
5.01	7.375	0.1709	0.1376
5.24	7.375	0.1832	0.1376
5.44	6.914	0.1856	0.129
6.11	6.062	0.2084	0.1131
5.96	7.375	0.2033	0.1376
5.34	6.146	0.1821	0.1147
5.12	6.062	0.1746	0.1131
5.05	7.375	0.1723	0.1376
5.37	5.531	0.1787	0.1032
5.2	7.375	0.1774	0.1376
5.18	7.375	0.1767	0.1376
5.34	7.375	0.1821	0.1376

The normalized decision matrix has been formed as shown in Table 4.

Table 5. Considered weightage of output response

Output Response	R_a	MRR
Weightage	0.5	0.5

Table 6. Weighted normalized decision matrix, Euclidian Distance & Relative Closeness

Weighted Normalized Output					
Surface roughness	MRR (mm^3/min)	S_i+	S_i-	P_i	Rank
0.0906	0.0688	0.0186	0.0376	0.6691	8
0.0913	0.0574	0.0281	0.0297	0.5145	17
0.0947	0.0645	0.0245	0.0317	0.5636	12
0.1066	0.0566	0.0387	0.0181	0.319	23
0.1049	0.0565	0.0375	0.019	0.3366	22
0.1099	0.0566	0.0413	0.0166	0.2868	25
0.1025	0.0566	0.0356	0.0206	0.3663	20
0.1006	0.0688	0.0268	0.0317	0.5419	14
0.1068	0.0688	0.0324	0.0291	0.4735	18
0.1112	0.0587	0.0411	0.0181	0.3062	24
0.1078	0.0516	0.0429	0.0134	0.2373	26
0.1163	0.0413	0.0562	0	0.0002	27
0.0788	0.0688	0.0129	0.0465	0.7827	2
0.0771	0.0816	0	0.0562	0.9997	1
0.0873	0.0688	0.0164	0.04	0.7094	5
0.0855	0.0688	0.0153	0.0413	0.7294	3
0.0916	0.0688	0.0194	0.037	0.6564	10
0.0928	0.0645	0.0232	0.033	0.5872	11
0.1042	0.0566	0.0369	0.0195	0.346	21
0.1017	0.0688	0.0277	0.0311	0.5288	15
0.0911	0.0574	0.028	0.0299	0.5168	16
0.0873	0.0566	0.027	0.0328	0.5484	13
0.0862	0.0688	0.0157	0.0408	0.7218	4
0.0894	0.0516	0.0324	0.0288	0.4705	19
0.0887	0.0688	0.0173	0.039	0.6927	7
0.0884	0.0688	0.0171	0.0392	0.6964	6
0.0911	0.0688	0.019	0.0373	0.6628	9

The closest and farthest points from the ideal solutions, or the Euclidian distance (S+&S-), are determined. The P_i value, or degree of proximity to the best solution, is calculated from these Euclidean distances, and the highest P_i value is indicated as the first ranking, while the lowest P_i value is marked as the final rank or the 27th rank. Table 7 lists the P_i values, Euclidian distances, Weighted Normalized Decision Matrix, and the corresponding rank assigned to each set of input parameters based on the P_i values.

Table 7. Summarized TOPSIS table ranking the set of input parameters

Test	Gap Voltage	Discharge current	Pulse On Time	Pulse Off Time	SR	MRR	S_i+	S_i-	P_i	Rank
1	25	10	35	5	5.31	7.3746	0.0186	0.0376	0.6691	8
2	25	10	35	8	5.35	6.1455	0.0281	0.0297	0.5145	17
3	25	10	35	9	5.55	6.9137	0.0245	0.0317	0.5636	12
4	30	15	50	5	6.25	11.0619	0.0387	0.0181	0.319	23
5	30	15	50	8	6.15	10.0563	0.0375	0.019	0.3366	22
6	30	15	50	9	6.44	11.0619	0.0413	0.0166	0.2868	25
7	100	20	100	5	6.01	11.0619	0.0356	0.0206	0.3663	20
8	100	20	100	8	5.9	7.3746	0.0268	0.0317	0.5419	14
9	100	20	100	9	6.26	7.3746	0.0324	0.0291	0.4735	18
10	25	15	100	5	6.52	12.2911	0.0411	0.0181	0.3062	24
11	25	15	100	8	6.32	5.531	0.0429	0.0134	0.2373	26
12	25	15	100	9	6.82	4.4248	0.0562	0	0.0002	27
13	30	20	35	5	4.62	7.3746	0.0129	0.0465	0.7827	2
14	30	20	35	8	4.52	14.7493	0	0.0562	0.9997	1
15	30	20	35	9	5.12	7.3746	0.0164	0.04	0.7094	5
16	100	10	50	5	5.01	7.3746	0.0153	0.0413	0.7294	3
17	100	10	50	8	5.24	7.3746	0.0194	0.037	0.6564	10
18	100	10	50	9	5.44	6.9137	0.0232	0.033	0.5872	11
19	25	20	50	5	6.11	11.0619	0.0369	0.0195	0.346	21
20	25	20	50	8	5.96	7.3746	0.0277	0.0311	0.5288	15
21	25	20	50	9	5.34	6.1455	0.028	0.0299	0.5168	16
22	30	10	100	5	5.12	11.0619	0.027	0.0328	0.5484	13
23	30	10	100	8	5.05	7.3746	0.0157	0.0408	0.7218	4
24	30	10	100	9	5.37	5.531	0.0324	0.0288	0.4705	19
25	100	15	35	5	5.2	7.3746	0.0173	0.039	0.6927	7
26	100	15	35	8	5.18	7.3746	0.0171	0.0392	0.6964	6
27	100	15	35	9	5.34	7.3746	0.019	0.0373	0.6628	9

From Table 7, Based on the relative closeness, we understand that Exp. 14 shows the best set of input parameters while Exp. 12 shows the worst results. The optimal input parameters for the combined EDM machining are shown in Table 8.

Table 8. The optimized set of input parameters (Weightage 0.5-0.5)

Gap Voltage	Discharge current	Pulse on Time	Pulse off Time
30	20	35	8

Confirmation Test:

The confirmation experiment is the last stage in the design of the experiment process's initial iteration. The verification experiment's purpose is to confirm the findings of the TOPSIS analysis phase. It is carried out by adjusting the process parameters to Voltage=30V, Discharge Current= 20A, Ton=35μs, Toff=8μs, as the optimum level and the actual surface roughness obtained is 6.34 μm to 4.52 μm and metal removal rate as 12.75 mm^3/min to 14.75 mm^3/min. Surface roughness and metal removal rate improvement shows that the accuracy of outcomes is increased by the TOPSIS multi-decision-making optimal design.

5. Conclusion

This study helped determine the ideal Shape Memory Alloy Electro Discharge Machine (EDM) parameters to optimize for low surface roughness (SR) and maximize metal removal rate (MRR). In these investigations, 27 sets of tests were carried out utilizing a copper electrode and an L_{27} Taguchi orthogonal array on shape memory alloy. Voltage, Discharge current, Pulse on time, and Pulse off time are some of the input parameters used. From the experiment and design of the experiment, the following conclusions were made; The many objectives are combined by Optimization using the Technique for order of preference (TOPSIS) into a single objective, and the optimum set of parameters, i.e., R_a & MRR, is provided. Table 6 lists the outcomes of the best solutions for both positive and negative ideal solutions. In Table 7, the output performances are sorted according to their proximity coefficient values. The largest MRR and the least amount of surface roughness are closer with the highest proximity coefficient value. By averaging the experiment data, the average proximity coefficient value for MRR and R_a is determined for levels 1-3. The shape memory alloy's MRR and Ra are determined in large part by the EDM machining parameters; among the parameters chosen, a larger current could produce enough discharge energy to melt and evaporate the reinforcement and matrix material. For the ideal good outcome, higher MRR and lower R_a are preferable. The results of the experiment show that voltage and discharge current have more effects. From the experiment, we get poor outcomes while keeping parameters set as Voltage=25V, Discharge Current= 15A, Ton=100μs, Toff=9 μs and best outcomes keeping parameters set as Voltage=30V, Discharge Current= 20A, Ton=35μs, Toff=8μs. Each performance is given a weight factor of 0.5. The optimum results obtained by the TOPSIS method for 0.5-0.5 weightage are as optimum surface roughness is 4.52 μm and metal removal rate as 14.75 mm^3/min by a combination of input parameters as Voltage=30V, Discharge Current= 20A, Ton=35μs, Toff=8μs. Confirmatory experiments show a satisfactory improvement of preference values utilizing TOPSIS in the EDM experimental and initial settings of 1.82.

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