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Optimize and Improve of The Welding Nugget in The Resistance Welding Process of Carbon Steel by Means of Surface Response Method

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الملخص

في مجال تطوير عمليات اللحام الآلي، احتل مجال اللحام مكانًا مرتفعًا مع زيادة الطلب على معدلات الإنتاج العالية والجودة والدقة. اللحام النقطي للفولاذ الكربوني يواجه بعض المشكلات مثل اختيار المعلمات المناسبة والمثلى لعملية الإدخال التي تتحكم في الظروف اللحام، مما يساعد على الحصول على الجودة المطلوبة أو التنبؤ بجودة وصلة اللحام.

في هذه الدراسة تم تطوير نموذج حسابي باستخدام برنامج (خبير التصميم 7.1) للحام النقطي بسماكة 2 مم لقطعة الشغل المصنوعة من الصلب الكربوني لربط عوامل التحكم في العملية اللحام مثل (تيار اللحام وقوة القطب الكهربائي ووقت اللحام). باستخدام طريقة سطح الاستجابة للتنبؤ وتحسين حجم الكتلة الملحومة في لحام البقعة المقاومة للفولاذ الكربوني. تم قياس كتلة اللحام ومعرفة تأثير القوة والتيار على عمق اختراق القطب (a). أظهرت نتائج الدراسة أنه يمكن استخدام منهجية سطح الاستجابة بسهولة لتطوير نماذج رياضية للتنبؤ بهندسة اللحام ,بالإضافة لقابليتها للتطبيق لعوامل عملية اللحام.

الكلمات المفتاحية: اللحام ، لحام البقعة المقاومة ، معلمات اللحام ، الفولاذ الكربوني ، التحسين.

ABSTRACT

In industry develop mechanized and automated welding processes, the welding field taken a high place with raising demand for high production rates, quality, and high precision. Some problem faces resistance spot welding of carbon steel such as selecting suitable and optimum parameters of input process that control conditions, which help to gain requirement nugget quality or predicting the nugget quality.

Mathematical models have been developed by (expert design program 7.1) utilizing the response surface methodology for the resistance spot welding of 2 mm thickness of carbon steel workpiece to relate important process control parameters like (welding current, electrode force as well as welding time) to an important nugget quality parameter. With utilize the response surface method to predict and optimizing the weld nugget volume in resistance spot welding of carbon steel. The weld nugget has been measured and finding out the effect of force and current on electrode penetrant depth (a). The study finding shown that the response surface methodology can be employed easily for developing mathematical models for predicting weld bead geometry within the workable region of process parameters.

Key Words: Welding, resistance spot welding, welding parameters, carbon steel, optimizing.

INTRODUCTION

Welding is a type of metal adhesion where adhesion is the result of heating to a suitable temperature, although the use of metal filler exists or does not exist according to the American Welding Associate [1]. According to American Society of Welding, welding is a localized coalescence of metal where coalescence is produced by heating to suitable temperature, with or without the use of filler metal [2-5]. Electrical resources including (electric arcs, electric resistance, electronic beams) and gas flames, lasers, friction, ultrasonic molten metal baths discover the many sources of energy that can be used in welding. The field of welding has a high position in the development of the industry. At a surprising rate, automation developed in the welding process, at the end of this century it is possible to discover more automation in welding processing units. Without a question about welding and this is important, we hardly understand that without welding this type of metal work and many metal structures like the building and the bridge will not be present. Therefore, the most important component in industries such as automotive, construction, and aviation is welding technology. In fact, oil is drilled at sea in addition to the use of various types of welding to work in such difficult ocean conditions [6-9].

In 1885, Elihu Thompson was discovered after melting some copper wire while experimenting with resistance welding. Later, based on those results, he patented an "Electric Soldering Tool" [10]. Resistance welding is the most followed by the electrical welding procedures used in today's industry. The welding process was due to a combination of heat, strength, time, and weight. In additional, resistance welding process suggests, the resistance of metals to electricity (welding current) leads to restricted heating. Conditions for the optimal welding process are the main component of the Taguchi method [11-15]. In general, in resistance welding, the heat generated in the welding area is the resistance next to the metal, which begins to weld with flowing electric current and also applies a certain pressure, to guarantee a sufficient contact area between the plate metal that needs welding. Unlike other welding processes, there is no filler metal in the local welding process or no fluxing materials are applied in the spot welding process. Resistance spot welding is commonly used as a welding process for manufacturing and manufacturing of the production industry. When choosing a process for private use, it is desperate to consider two conditions as follows [16].

- To obtain the required specifications, the welding parameters must be controlled and optimized to maximize the formation of the welding area.
- The ability to perform welds of the required quality through long-term production at a low operating cost.

The current path in these work pieces is welded and the need for some heat and low voltage is relatively high, currents are important to improve the required amount of welding heat. This study aims to use the response surface method to predict and improve the size of weldment parts in carbon steel spot welding.

EXPERIMENTAL

- **Materials**

Carbon steel were used as experimental metal; the chemical compositions of the Carbon Steel are given in the Table 1.

Table 1. The chemical compositions of carbon steel

Content	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Ca	Ce	La	Pd	Fe
%	.059	.013	.014	.016	.146	.062	.029	.016	.050	.0030	.014	.003	.003	99.401

- **Welding and Welding Equipment**

The raw metals of carbon steel are formed in form of plate of 20 cm length, 2.5 cm width and 2mm thickness by used low speed with cooling solution to avoid generated temperature and stress concentration during forming process, the dimensions of samples gross section as showing in figure (1):

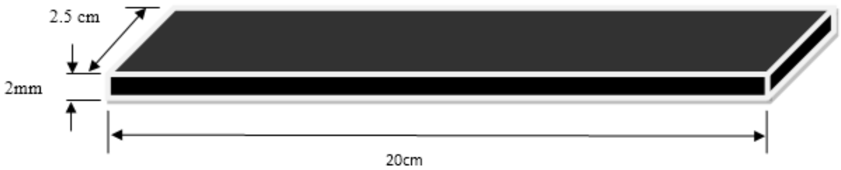

Figure 1. Dimensions of row material specimen.

Resistance Spot welding RSW is made by spot welding machine which is (Rayomex PMI-2045 Spot welder, Manual Spot Welding Machine), where control panel in welding machine are prepare to adjust settings for welding process parameters like welding time and speed. The control parameters were (Current, Time, and Force), the parameters changed to find good weldability and the effect of minimum temperature on the welding areas between the minerals, the table 2 shows the parameters of the welding process for better welding.

Table 2. The welding process parameters.

No.	Current (A)	Force (N)	Time (s)
1	30	5	1.5
2	50	5	1.5
3	30	10	1.5
4	50	10	1.5
5	30	5	2.5
6	50	5	2.5
7	30	10	2.5
8	50	10	2.5
9	23	7.5	2
10	50	7.5	2
11	40	4	2

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12	40	12	2
13	40	7.5	1
14	40	7.5	3
15	40	7.5	2
16	40	7.5	2
18	40	7.5	2
19	40	7.5	2
20	40	7.5	2

Changing one parameter at a time and keeping the other parameters constant. The scope of work was determined by inspecting for any visible defects, such as cracks and porosity. The upper and lower variables of the process control are shown in Table 3.

Table 3. The process control variables.

Control Variables	lower	upper
Current (A)	23	55
Force (N)	4	12
Time (s)	1	3

- **The Measurement of Weld Size**

Mainly, weld size measurements were made through the metal cross sections of the weld nugget samples through image analysis using a small digital holographic endoscopy. The cross section of the sample weld, where the melting area and the measured weld size were made.

RESULTS AND DISCUSSIONS

- **Visual Examinations**

The most widely used of any welding methods of nondestructive examination, where the visual examination is easy to apply, quick, inexpensive. On other hand, required experience and gives important information related to the general conformity of the weldment to specifications and standards. Visual examinations and inspection was done for all samples and show some defects as the welding parameters effects. All resistance spot welding sample have good penetration, Figures 2&3 showing some samples after welding process. Where, the samples dimensions were shown in Figure 1.

Figure 2. Samples after welding process.

Figure 3. Samples after welding process.

- **Macrostructure Test Discussions**

To determining the quality of the weld area depends largely on the requirements of the relevant examination and test, Destructive Testing used for any weld production. In general, the specifications require mechanical tests of weld area resistance, weld properties, sizes, and HAZ to determine the quality of weld regions.

Mechanical tests of the weld area are similar to those applied to base metals, and in some cases change as necessary to determine the characteristics of the weld regions. Table 4 shows that the weld area measurement samples with (a), (d) and (D) are shown in the following figure. As shown in Figure 4.

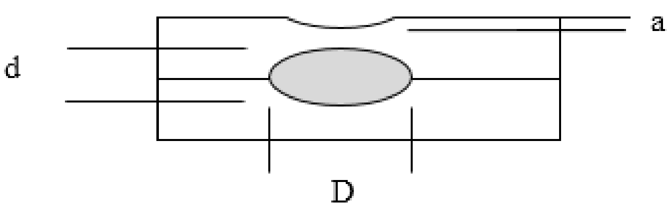

Figure 4. Cross-section of welding zone.

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Where:

- a = Electrode penetrant depth
- d = Height of nugget
- D= Width of nugget

Table 4. The samples welding area measurement.

NO	Current A	Force N	Time s	a	d	D
1	30	5	1.5	3.58	4.18	0.13
2	50	5	1.5	4.45	4.09	0.08
3	30	10	1.5	4.12	4.13	0.1
4	50	10	1.5	5.09	4.01	0.05
5	30	5	2.5	4.26	4.05	0.13
6	50	5	2.5	4.25	3.96	0.18
7	30	10	2.5	4.85	4.09	0.81
8	50	10	2.5	6.10	4.25	0.20
9	23	7.5	2	7.32	11.11	0.22
10	55	7.5	2	5.06	4.05	0.35
11	40	4	2	4.93	4.08	0.16
12	40	12	2	5.54	3.99	0.19
13	40	7.5	1	5.54	3.99	0.19
14	40	7.5	3	5.71	4.40	0.11
15	40	7.5	2	4.45	4.08	0.11
16	40	7.5	2	3.68	4.33	0.18
17	40	7.5	2	4.42	4.33	0.16
18	40	7.5	2	5.65	4.17	0.26
19	40	7.5	2	5.36	4.06	0.21
20	40	7.5	2	5.47	4.10	0.49

The selected process control variables with their limits and codes are given in Table 5.

Table 5. The control variables with their limits

Parameter	Notation	Factor levels				
Coded value		-1.6	-1	0	1	1.6
Current	C	23	30	40	50	55
Force	F	4	5	7.5	10	12
Time	T	1	1.5	2	2.5	3

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The experiments were carried out according to the random design matrix, to avoid the systematic errors that infiltrate the system model. The beads are placed on the hinge to hold the 2mm thick carbon steel plates in the experimental setup shown above.

- **DEVELOPMENT OF MATHEMATICAL MODELS**

Improve the results obtained by the expert design program 7.1. Whereas, (Design Expert) is part of a design program that needs the researcher's help to design and interpret multivariate research experiences. It is used to design an experiment to see how properties such as tensile strength affects changes in treatment conditions. The program provided a wide range of experimental designs containing factors, fractional factors, and complex designs that can deal with both process parameters such as welding speed and other process parameters. The response function representing any of the weld dimensions can be expressed as:

y = f [current (C), resistance (F), time (T)]

The chosen relationship, being a second degree response surface, is expressed in the equation model [1]. Also, as shown in Figure 4.

$$Y = b_0 + b_1C + b_2F + b_3T + b_{11}C_2 + b_{22}F_2 + b_{33}T_2 + b_{12}CF + b_{13}CT + b_{23}FT$$
(1)

Where: b_0 is the average of responses and b_1, b_2, b_3, b_{11}, b_{13}… b_{33} are the coefficients that depend on the respective main and interaction effects of parameters. The mathematical models developed are given below. The process control variables are in their coded form:

$$a = 0.2 + 0.036C + 0.034F + 0T + 0.03CF - 0.02CT - 0.018FT + 0.028C_2 - 0.021F_2 + 0.021T_2$$
(2)

$$d = 4.14 - 13C - 0.03F + 0.073T - 0.035CF + 0.1CT + 0.12FT - 0.11C_2 - 0.027F_2 + 0.025T_2$$
(3)

$$D = 4.84 + 0.26C + 0.18F + 0.49T - 0.088CF + 0.18CT + 0.24FT - 0.41C_2 + 0.21F_2 - 0.07T_2$$
(4)

NO	C	F	T	Current	Force	Time	a	d	D
1	-1	-1	-1	30	5	1.5	3.58	4.18	0.13
2	+1	-1	-1	50	5	1.5	4.45	4.09	0.08
3	-1	+1	-1	30	10	1.5	4.12	4.13	0.1
4	+1	+1	-1	50	10	1.5	5.09	4.01	0.05
5	-1	-1	+1	30	5	2.5	4.26	4.05	0.13
6	+1	-1	+1	50	5	2.5	4.25	3.96	0.18
7	-1	+1	+1	30	10	2.5	4.85	4.09	0.81
8	+1	+1	+1	50	10	2.5	6.10	4.25	0.20
9	-1.6	0	0	23	7.5	2	7.32	11.11	0.22
10	+1.6	0	0	55	7.5	2	5.06	4.05	0.35
11	0	-1.6	0	40	4	2	4.93	4.08	0.16
12	0	+1.6	0	40	12	2	5.54	3.99	0.19
13	0	0	-1.6	40	7.5	1	5.54	3.99	0.19
14	0	0	+1.6	40	7.5	3	5.71	4.40	0.11
15	0	0	0	40	7.5	2	4.45	4.08	0.11
16	0	0	0	40	7.5	2	3.68	4.33	0.18
17	0	0	0	40	7.5	2	4.42	4.33	0.16
18	0	0	0	40	7.5	2	5.65	4.17	0.26
19	0	0	0	40	7.5	2	5.36	4.06	0.21
20	0	0	0	40	7.5	2	5.47	4.10	0.49

Table 6. The design matrix and observed values of the bead dimensions.

Effect of force and current on electrode penetrant depth (a)

The optimization of the resistance spot welding parameters was implemented using the statistical tool Response Surface Methodology (RSM). It is a set of mathematical and statistical methods useful for developing a set of experiments, establishing an empirical relationship and graphically indicating the effect of the interaction between the values of the process parameters. The penetration depth of the electrode (a) increases with increasing resistance (F), and this gradually increases with increasing current (C) in relation to time (T). Because F, C and T have a positive effect on the penetration depth of the electrode (a), as seen in Figures.

Figure 5 shows the response surface and contour surface of electrode penetrant depth (a) for the interaction effect of F and C. While Figure 6 represent the relationship between time F and current C. In addition, Figure 7 shows the response surface and contour surface of electrode penetrant depth (a) for the interaction effect of time T and current C. while figure 8 represent the relationship between time T and current C. In other side, figure 9 shows the response surface and contour surface of electrode penetrant depth (a) for the interaction effect of time T and force F. While, figure 10 represent the relationship between time T and force F.

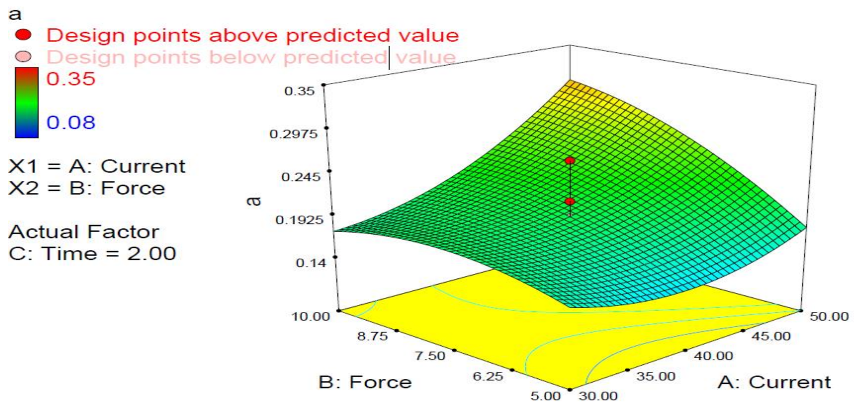

Figure 5. Electrode Penetrant depth (a) for interaction effect of F & C.

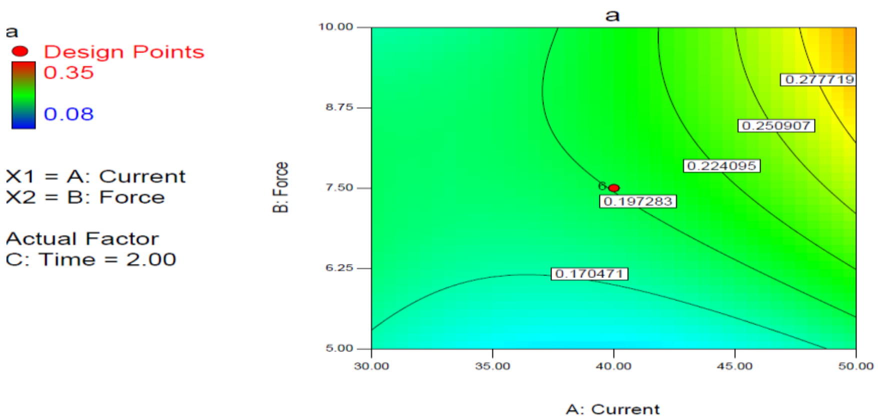

Figure 6. Represent the relationship between time F and current C.

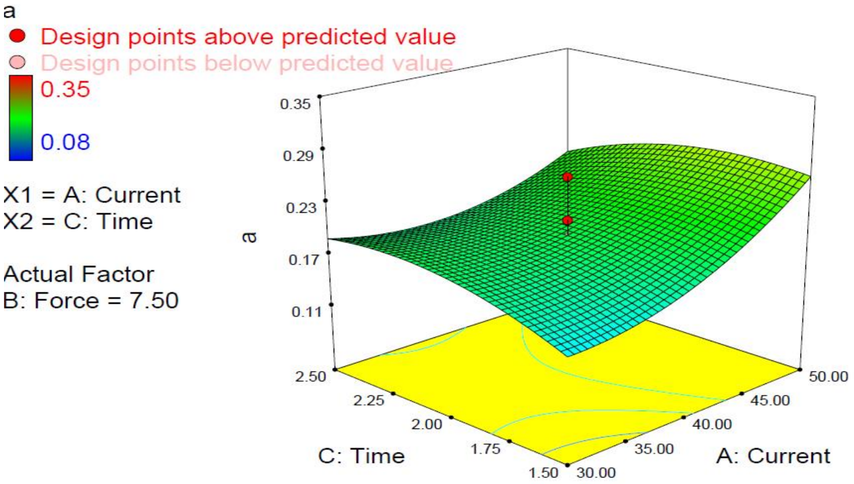

Figure 7. Electrode penetrant depth (a) for effect of time T and current C.

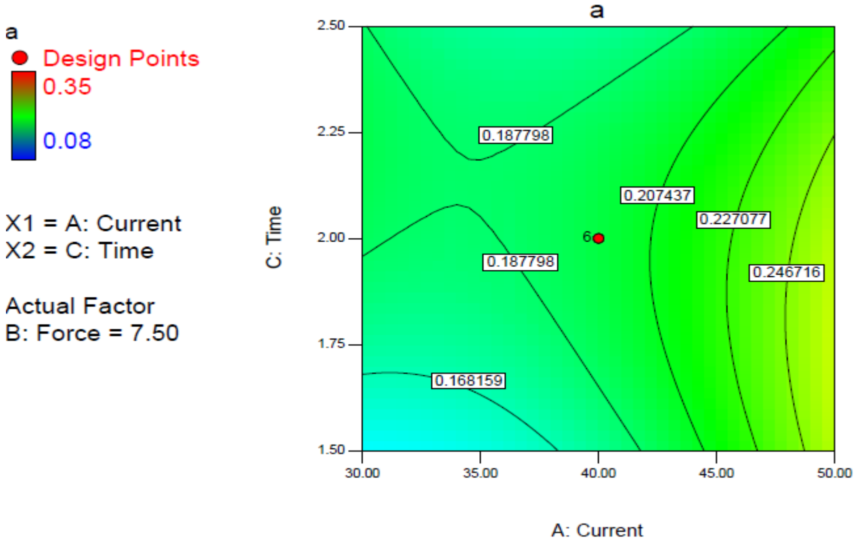

Figure 8. Represent the relationship between time T and current C.

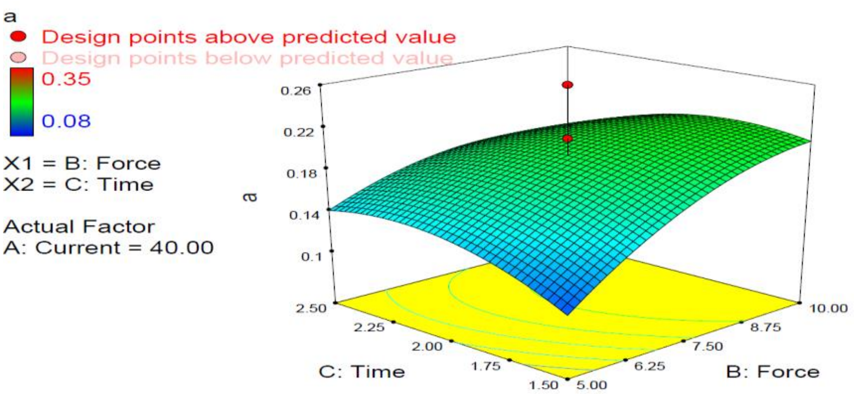

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Figure 9. Electrode Penetrant depth (a) for effect of time T and force F.

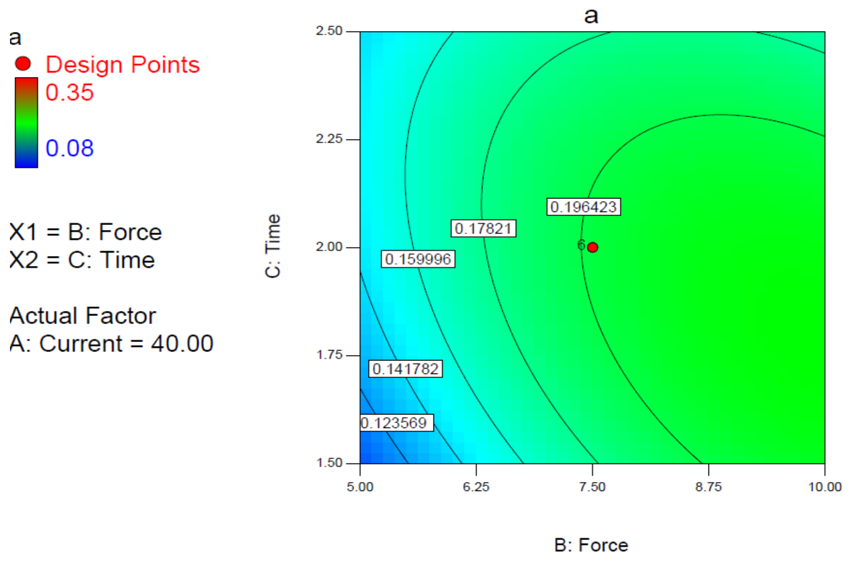

Figure 10. The represent the relationship between time T and force F.

CONCLUSIONS

This study taken the important from title itself, which aimed to utilize the response surface method to predict and optimizing the weld nugget volume in resistance spot welding of carbon steel. As well as, measuring weld nugget to finding out the effect of force and current on electrode penetrant depth (a). the study finding shown that the response surface methodology can be employed easily for developing mathematical models for predicting weld bead geometry within the workable region of process parameters. The models developed can be employed easily in the form of a program for automatic and robotic welding for obtaining the desired high-quality welds.

The predicted values of nugget size are in good agreement with the actual experimental values. The all nugget parameters are increases with the increase in current, force and time. The best dimensions have been found were width (D)=4.28 mm, height (d)=3.91 mm and electrode penetrant depth (a)=0.16 mm corresponding to input process parameters, current (C)=18.18 A, force (F)=7.7 N and time (T) = 1.5 s.

This work could be applied on other materials and on other welding processes even those with filler metals. This work could be extended to study the influence of parameter on other responses like heat affected zone, hardness and distortion

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