

Transient Thermal Analysis of Welding Fixtures Design

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Abstract. This paper presents the design and analysis of welding fixtures based on transient thermal analysis. Welding fixtures is designed to hold and support the workpiece securely during the welding process. The heat transformation from the workpiece could lead the temperature rises and impacts to the welding fixtures. Therefore, the study introduces the development of welding fixtures as one of a safety measure prevents the welder from injury while handling welding process. The conceptual design of welding fixtures and material were applied to conduct the simulation. Transient thermal analysis was performed on temperature and total heat flux by using computer aided engineering software. The result shows the analysis of equivalent stress, total deformation, factors of safety, fatigue life and fatigue damage. Furthermore, the equivalent stress failure theory used to predict yielding in welding fixture design. The design of welding fixtures and material selection were proposed to hold and support the workpiece securely.

Keywords: Transient, Thermal, Design, Fixture, Welding

1. Introduction

The fixture design has been attracted by the researchers and engineers due to relevance with the best practice in manufacturing industries. At the moment, fixture has become an important role for ensuring the manufacturing processes could performs at the high level of productivity. Most of cases in Malaysia, the fixture is designed to increase the productivity form the perspective of making the target unit produced at the high level. The fixture design is well-defined as a tool or support the holding of a workpieces [1]. The fixture is created depends on the process involve on the workpieces. Frequently, for the process of inspecting the workpiece, using the fixture design as assemble the part, machining process, and welding process [2].

The common practice in fixture design is to study the fatigue analysis [3]. Feng, and Yong-hai were studied the important of fatigue life analysis and found a method of finite element to design of a new semi-trailer frame. Another study was explained a clamps and locator used in welding fixture is to



coordinate and maintain various pieces for welding process. The welding equipment is designed and fabricated to meet specific needs of a single assembly. Usually, there are very expensive when designing the welding equipment and more complicated than the design when manufactured the fixtures. Most of the researchers and authors were explained that it takes a long time to produce a new design and fitting of welding equipment at the manufacturing, particularly in the design stage. [1-3].

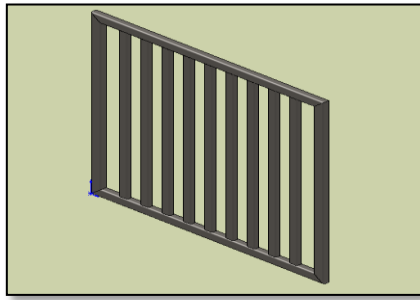
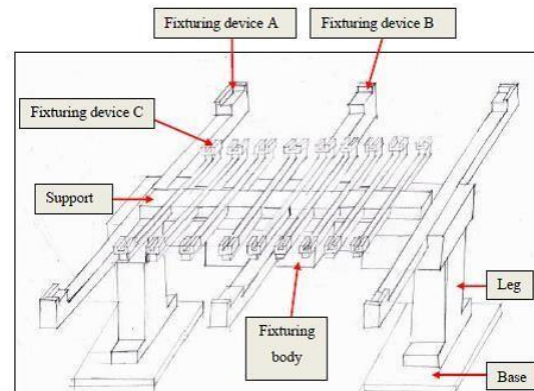
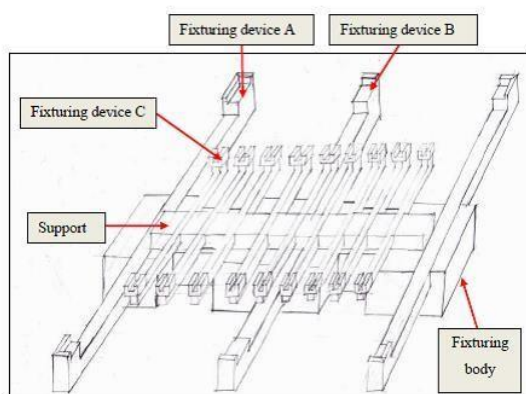
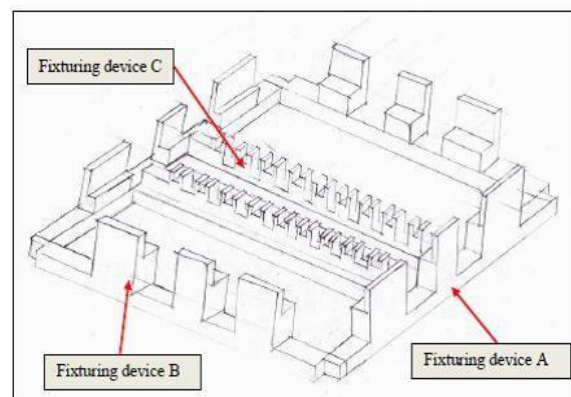
The manufacturing engineers usually uses their experience in designing the fixture. In the field of welding fixture is designed in two processes automatically and manually. For the welding fixture is widely used in the automotive field for making an automotive body in the welding assembly line. The study of manufacturing system cost, particularly in producing the fixtures is about to 10-20% of manufacturing cost [1]. As consequently, a fixture system is designed and manufactured for producing as many workpieces as possible to reduce the manufacturing cost as a main purpose. In term of manufacturing, the fixture are suited in large production and low-to-medium production due to some reasons such as to meet the size ratio of fixture and workpiece. Another reason is to support the flexible fixture system to improve and to reduce the product unit cost [4]. The prediction of bead geometry was introduced by Kanti and Rao in 2008 [5] and proposed the GMA welding using propagation neural network. Most of technique has been introduced by the authors Baskharone in 2012 [6] and Cengel in 2011 [7], and stated that the necessity of thermal and heat transfer to be included in designing a product.

In the fixture system, the gate has been made a necessary role for safety and protection due to main purposes in joining processes. The welding process is the best manufacturing process to join several gates or parts due to simple and economic way. The main problem in the welding process is found that there were lack of an accuracy from the welder. The fixture design is on the solution in order to increase the welder accuracy during welding processes. The purpose of fixture design is to hold and support the workpiece during assembly processes. However, there is a lack of study in designing of fixture. In this research, the new design of welding fixture and the best material selection based on research were proposed. The motivation of this research is to design and analysis of welding fixtures from different perspective of low cost in developing the fixtures design. In addition, several design analysis was conducted to ensure the fixture material could withstand the standard welding temperature and the dynamic load conditions.

2. Materials and Methods

There are methodology and material proposed, and the suitable workpiece for welding fixture was selected as shown in Figure 1. The workpiece was designed with two different size of rectangular hollow steel, with the size of 40x60x4 mm and 30x50x4 mm. The mass properties of workpiece are identified with 77,019.77 grams or equivalent with value of 755.56 N. The total force of 755.56N is designed as workpiece and is applied to the fixture. In this study, ASTM A500 grade A also known as 1027 plain carbon steel is selected for the workpiece. This material also is chosen due to suitable for all standard welding process practically.

For the second stage, the generation of design concept was created in Figure 2, 3, and 4. The fixture function is designed to hold the workpiece while the joining process on the workpiece. The fixture design is based on workpiece parameter and process assembly. There are three concepts sketch of the design have been developed and to be selected using the concept selection process to choose the best of design concept.

**Figure 1.** Workpiece**Figure 2.** Design concept 1**Figure 3.** Design concept 2**Figure 4.** Design concept 3

In third stage, it is the selection process in order to determine the design concept based on the criteria ease to assemble, attachable, holding ability, ergonomics, accuracy, number of parts and structure durability. The criteria were taken into account based on the observation in Malaysia manufacturing industry. Table 1 lists the selection of design concept on the specific criteria are used in this study. The rating was given using the interview from the engineers who involved in this working area.

Table 1. Selection of design concept

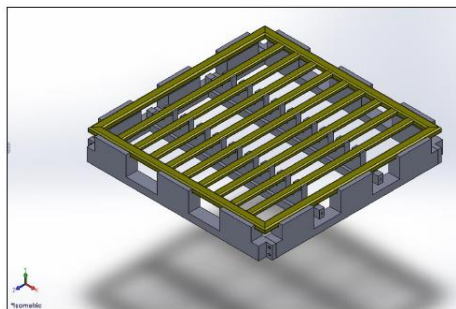
Selection criteria	Weight	Rating	CONCEPT A		CONCEPT B		CONCEPT C	
			Weight score	Rating	Weight score	Rating	Weight score	Rating
Ease to Assemble	16%	3	0.48	4	0.64	5	0.80	
Ease of attachment	10%	0	0.00	4	0.64	2	0.32	
Holding ability	18%	5	0.80	5	0.80	5	0.80	
Ergonomic aspects	10%	5	0.80	3	0.48	3	0.48	
Value of accuracy	16%	4	0.64	4	0.64	4	0.64	
Number of part	12%	2	0.32	3	0.48	4	0.64	
Structure durability	18%	4	0.64	2	0.32	5	0.80	
Total score			3.68		4.00		4.48	
Continue-Yes/No			No		No		Yes	

Table 2. Material properties [8]

Analysis	Selected material properties	Unit	Material		
			Low Carbon Steel	Cast Iron (Ductile)	Stainless Steel
Static Structural Analysis	Density	Kg/m ³	7850	7150	7850
	Young Modulus	GPa	207.5	172.5	199.5
	Poisson Ratio	-	0.29	0.27	0.270
	Tensile Strength, yield	MPa	345	410	480
	Tensile Strength, ultimate	MPa	580	830	2240
	Compressive Strength, yield	MPa	250	250	170
	Compressive Strength, ultimate	MPa	395	790	1000
	Density	Kg/m ³	7850	7150	7850
Transient Thermal Analysis	Thermal Conductivity	W/m.k	51.5	36.5	18
	Specific Heat	J/kg.k	482.5	477.5	490

Based on the Table 1, design concept 3 has the highest value and selected to be developed in this study.

The next step is to design the 3D model for the selected design concept. Figure 5 shows the 3D model for selected design concept.

**Figure 5.** 3D model

In designing of fixture, one of important factor is the capability to choose the suitable material for particular function. It is presented that, three candidate materials have been chosen: Low carbon steel, cast iron (ductile) and stainless steel. All the materials proposed are suitable for fixture design. Furthermore, the durability and holding ability were the highest criteria to choose the suitable design concept due to the high level important in fixture design. Table 2 shows the requirement that used to make the finite element analysis.

3. RESULTS AND DISCUSSIONS

The simulation results were showed the temperature distribution and total heat flux in transient thermal analysis. The simulation result is presented as a result from ANSYS software. Figure 6

represents the contrast between global maximum and minimum temperature for stainless steel material. The initial temperature is achieved with value of 924°C and it is applied to this fixture surface area. Based on the simulation, it is found that the green line represents the maximum global temperature while the red line represent as minimum global temperature. The temperature increases until it reaches the maximum temperature of 959.85°C at 3.34 seconds in the global maximum temperature. While for the global minimum temperature, the temperature can reach to 753.56°C. In addition, Figure 6 shows a sign of cooling in 10 seconds significantly. For the other materials have similar pattern with stainless steel and the pattern of minimum temperature shows the ability of this material to absorb the heat from the workpiece and transferred in surrounding.

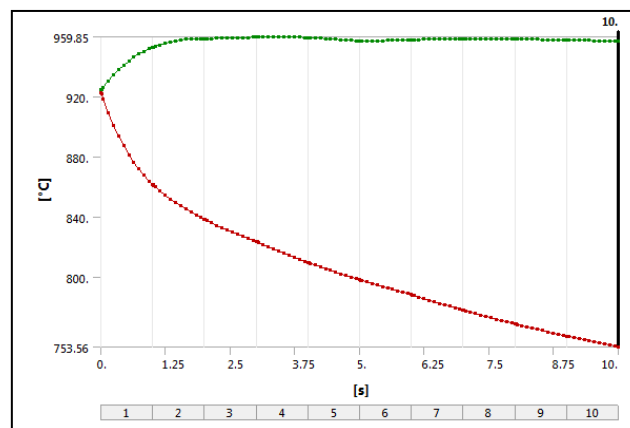


Figure 6. Comparison between global maximum and minimum temperature for stainless steel

The phenomena of temperature distribution for stainless steels material is presented in Figure 7. It is found that the maximum temperature is achieved with 959.85 °C, and the minimum temperature is reached with 753.56°C at 10 seconds. The result depicts none of red colour found in the fixture design. In the meantime, the blue colour appears and it is found that the deformation could not performed on this fixture design. In addition, the figure shows a heat flow throughout all body welding fixture with illustrated in brown colour. The result shows an ability of this material to transfer heat from the workpiece to the fixture performed at the high level of temperature rises and drops significantly.

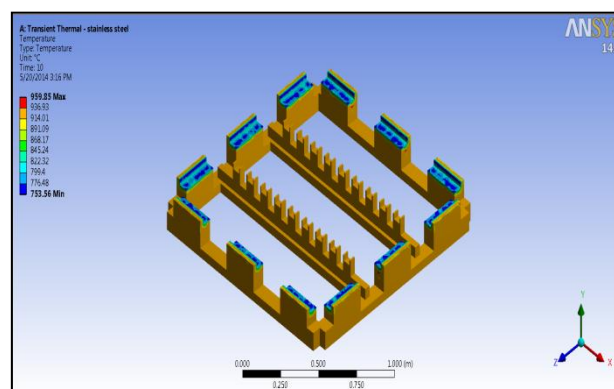


Figure 7. The temperature distribution for stainless steel material

The maximum heat flux for stainless steel material is achieved with 3.41910 W/m² while the minimum heat flux is reached with 0.00076172 W/m² at 10 seconds. Figure 7 shows the detail of temperature distribution and the phenomena of transient thermal for stainless steel fixture design.

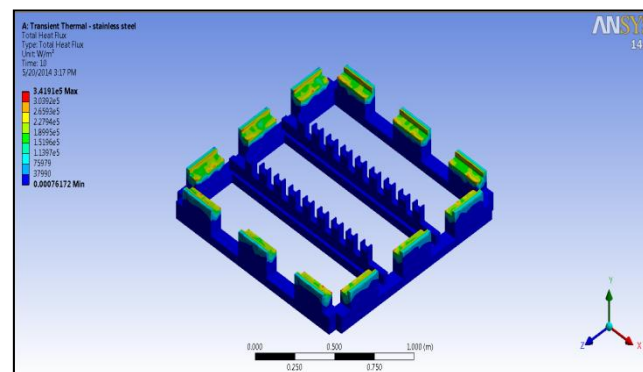


Figure 8. The total heat flux for stainless steel material

There are two analysis is carried out using three different materials for this part. For static structural analysis, result of fatigue life and fatigue damage is similar for the three materials. This means that, all the three candidate materials have a life of infinity ($N > 1 \times 10^6$ cycles) and very suitable for this part to receive the load in dynamic condition (loading and unloading workpiece). Furthermore, fatigue damage also has a same value for all candidates of material where the value is 1000 cycle. Table 3 shows the comparison maximum equivalent stress and elastic limit for three candidate materials that to be designed for welding fixture

Table 3. Comparison maximum equivalent stress and elastic limit (yield strength) for welding fixture

Material	Max equivalent stress	Elastic limit (yield strength)
Low Carbon Steel	590.05 Pa	322500000 Pa
Stainless Steel	586.68 Pa	585000000 Pa
Cast Iron (Ductile)	593.72 Pa	465000000 Pa

In addition, the maximum equivalent stress is used to calculate the safety factor of each material. Based on the obtained result, all material is safe to use because the elastic limit (yield stress) for each material is larger than the maximum equivalent stress as shown in Table 4.

Table 4. Comparison between total deformation and factor of safety for welding fixture

Material	Total Deformation	Factor of Safety (F.O.S)
Low Carbon Steel	0.000000044404 m	982967.5451
Stainless Steel	0.00000000047268 m	3818095.043
Cast Iron (Ductile)	0.00000000053944 m	1397965.371

The best material is selected based on the total deformation and safety factor of each material. Based on the result obtained, stainless steel produce the lowest deformation of 0.00000000047268 m compared to other materials. Meanwhile, the low carbon steel produces the highest deformation of 0.000000044404 m. Therefore, the material has the lowest deformation was selected due to sufficient to its function and economic reason.

The selection of the best material also refers to the factor of safety. Based on the Table 4, the highest value of safety factor is 3818095.043 for stainless steel, while the lowest is 1397965.371 for cast iron (Ductile). Therefore, the highest safety factor is better and that is not good if the safety factor is less than 0. After making comparisons between the three candidate materials in static structural analysis, it is found that the best material used for welding fixtures is stainless steel. It means that the other materials are not good than stainless steel and not suitable for use. It is due to the criteria to be selected is based on the lowest amount of deformation and the highest factor of safety.

The other analysis is transient thermal analysis. In this research, the selection of the best material is also based on transient thermal analysis result. There are two result discussed which is temperature distribution and total heat flux to determine the durability of candidate material during the welding process on the workpiece. Both of result also combined with the best result of the static structural analysis in order to select the best material for welding fixtures.

This study met the results given by Ahmed and Saha (2018) [9] that fixturing issues were influenced in joining of thin sheets. In addition the authors studied the fixtures in order to hold the thin sheets close to the weld line with precision and uniform pressure. Another study on the effects of welding condition on weld shape and distortion in electron beam welded was introduced, and it is found that three-dimensional thermal-elastic-plastic finite element method was developed to simulate the welding distortion [10]. Thermal analysis in this study shows significantly by using thermal simulation and it is found the economic way to select suitable material for welding fixture.

The fixture design is required to be further study in designing for friction stir welding due to affected to the final product [11]. In recent, the study of weld zone and residual stress development in AA7050 stationary shoulder friction stir T-joint weld was introduced [12]. It is found that thermal analysis of welding fixture was significantly improved the quality of final product.

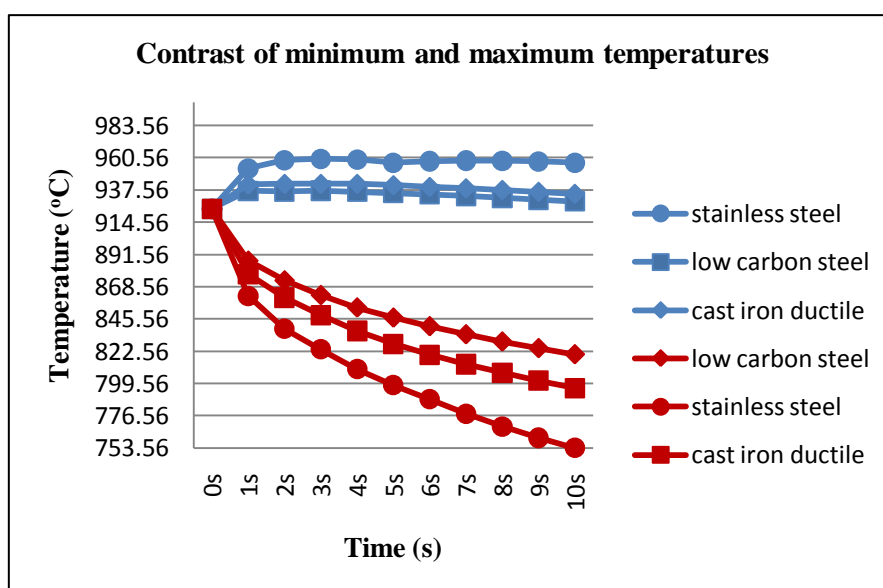


Figure 9. The comparison of minimum and maximum temperatures

In Figure 9, the optimal comparison of minimum and maximum temperatures for proposed materials is achieved in 10 seconds significantly. In addition, the lowest temperature is achieved with 753.56°C. Therefore, it is found that the stainless steel cools rapidly from the maximum temperature 959.85°C to 753.56°C in 10 second. Furthermore, it also shows that stainless steel material able to release the heat quickly after receiving the heat during the welding process.

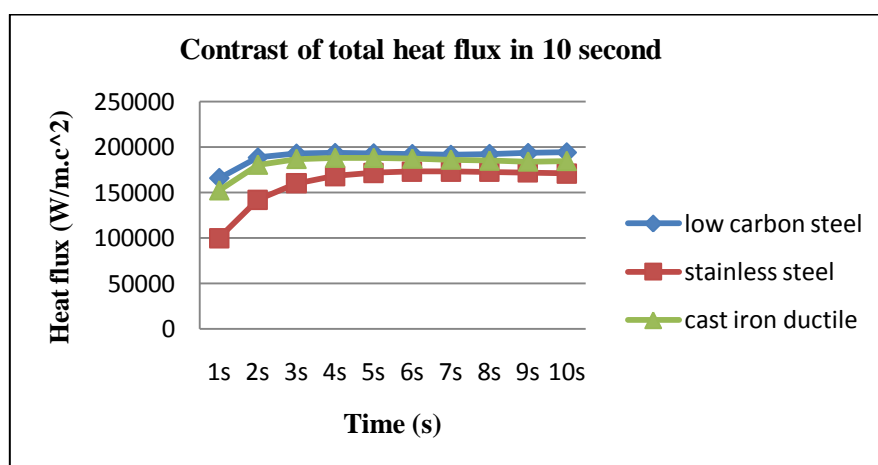


Figure 10. Contrast of total heat flux in 10 second

Figure 10 shows the comparison of total heat flux for candidate materials in 10 seconds. Candidate selection of the best material is based on the lowest total heat flux. From the graph, the lowest heat flux is 170 955 W / m² for stainless steel while the highest heat flux is 193 970 W / m² for low carbon steel at 10 seconds. Therefore, the selected material is stainless steel which has the lowest total heat flux from 99 735 to 170 955 W / m² in 10 seconds.

As a result of discussions for welding fixtures, the best material for all result from both analyses is stainless steel. Therefore, stainless steel is selected for welding fixtures which has less deformation, highest factor of safety, lowest in global temperature and the lowest total heat flux compared from the other material. This material fulfils all the criteria and more ability to withstand the heat applied and the force exerted on the welding fixtures.

There are only one analysis is carried out using three different materials for this part. Based on the result, fatigue life and fatigue damage also similar for the three materials. This means that, all the 3 candidate material have a life of infinity ($N > 1 \times 10^6$ cycles) and very suitable for this part to receive the load in dynamic condition (loading and unloading workpiece). Furthermore, fatigue damage also has a same value for all candidates of material where the value is 1000 cycle. The fatigue life result obtained was relevant with Feng, and Yong-hai [3], and showed the necessity fatigue life in designing of a product.

Table 5. Comparison maximum equivalent stress and elastic limit (yield strength) for welding fixture

Material	Max equivalent stress	Elastic limit (yield strength)
Low Carbon Steel	1615.3 Pa	322500000 Pa
Stainless Steel	1615.1 Pa	585000000 Pa
Cast Iron (Ductile)	1615.1 Pa	465000000 Pa

Table 5 lists the maximum equivalent stress is used to calculate the safety factor of each material. Based on the obtained result, all material is safe to use because the elastic limit (yield stress) for each material is larger than the maximum equivalent stress as shown in Table 5.

Table 6. Comparison between total deformation and factor of safety for welding fixture

Material	Total Deformation	Factor of Safety (F.O.S)
Low Carbon Steel	6.425×10^{-8} m	359066.427
Stainless Steel	6.869×10^{-10} m	1386911.027
Cast Iron (Ductile)	6.869×10^{-10} m	513900.068

The best material is selected based on the total deformation and safety factor of each material as shown in Table 6. Based on the result obtained, stainless steel and cast iron (ductile) has produced the similar deformation of 6.869×10^{-10} m. Meanwhile, the low carbon steel produces the highest deformation of 6.425×10^{-8} m. Therefore, material having lowest deformation is the best in this selection. The selection of the best material also refers to the factor of safety. Based on the Table 6, the highest value of safety factor is 1386911.027 for stainless steel, while the lowest is 359066.427 for cast iron (Ductile). Therefore, the highest safety factor is better and that is not good if the safety factor is less than zero value.

After making comparisons between the three candidate materials, it is found that the best material for welding fixtures is stainless steel. Although the deformation that occurs in stainless steel and cast iron (ductile) is similar, the stainless steel is the best material for welding fixtures because the safety factor for stainless steel is better than cast iron (ductile). In addition, it does not mean the others material are not good than stainless steel and not suitable for use, but to select the best material from the three candidates material, it must have the lowest amount of deformation and the highest factor of safety.

4. CONCLUSION

The design parameters of new welding fixture such as the type of welding fixtures, the workpiece used to the welding fixture, the type of welding used, and the design planning that influences the welding fixture base on dynamic load condition were investigated. Design concept 3 was selected to be developed and conducted the simulation analysis.

Based on the simulation result, the three candidate materials are suitable for welding fixtures where it can withstand the load and heat generated on this part. The best material selected is stainless steel on both the analysis for welding fixtures. The transient thermal analysis, the selected material also stainless steel which has less temperature distribution and the lowest total heat flux. Therefore, the final selection of the best materials for welding fixtures between both analyses is stainless steel.

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