# Design and Analysis of Three-Link Arms Robot By Using Steel, En-9, and Al-7075

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## ABSTRACT

Industrial robots are normally composed of links that are combined by rotary or prismatic joints to form a kinematic chain. As such, there are several possible techniques to build industrial robots using those two types of joints. The elbow manipulator, which is also named articulated or revolute manipulator, is constructed using three links connected by the rotary joints that are useful to allow motion in different directions.In this paperthe articulated manipulator was designed using CAD-tool (CREO-2) and then analyzed (by using ANSYS workbench) with the real time boundary conditions. Three types of materials (Steel, En-9, and Al-7075) were used to estimate the static analysis like: deformation, stress, shear stress and safety factor values. It would be also concluded which metal has better specifications. In order to calculate the real time resultsthe designed model was examined with dynamic analysis which can help to find the deformation, velocity and acceleration of the robot arm.

**Key words:** Elbow manipulator, CREO-2, ANSYS workbench, Static, Dynamic, En-9, Steel, and Al-7075.

# تصميم وتحليل ذراع روبوت ذو ثلاثة وصلات باستخدام Steel, En-9, and Al-7075

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## المستخلص

تتكون الروبوتات الصناعية من وصلات متصلة بواسطة مفاصل دورانية أو خطية ، ولهذا هناك العديد من التقنيات الممكنة لتصميم الروبوتات الصناعية بأستخدام هذين النوعين من المفاصل. تشكل الروبوتات المفصلية بأستخدام ثلاثة وصلات مربوطة بمفاصل دورانية والتي تسمح بالحركة في أتجاهات مختلفة.في هذا البحث تم تصميم روبوت مفصلي باستخدام برنامج (CREO-2) ومن ثم تحليله بأستخدام برنامج (ANSYS WORKBENCH). أستخدمت ثلاثة أنواع من المواد (Steel, En-9, and Al-7075) لتقييم التشوه والاجهاد واجهاد القص وعامل الامان. سوف يتم ايضا استخلاص اي معدن يمتلك افضل مواصفات لبناء الروبوت. تم ايضا تقييم نتائج التحليل الديناميكي للنموذج المصمم في ظروف العمل الحقيقيه والذي يساعد على ايجاد قيم التشوه والسرعة والتعجيل لذراع الروبوت.

# 1. Introduction

Robotics is a relatively new area of modern technology that deals with reprogrammable, multifunctional machines [1]. Robots are typically employed to achievedifficult, hazardous tasks that need complex motion. Tasks like welding, lift heavy objects, grinding, paint, and assembly are probable applications that robot manipulators can perform. Industrial manipulators normally have 6 degree of freedom (DOF) or less and they fall into one of five geometry types: articulated, SCARA, spherical, Cartesian and cylindrical manipulator [1]. The articulated manipulator has three links that are nominated as the body, upper arm and forearm. Those links are coupled by revolute joints that are useful to allow motion in different directions. Many researchers have designed and analyzed the industrial robot manipulator. For instance, Tanneeru, *et al.*[2] designed a single DOF motorized robot arm that could be controlled by a remote control. The authors also used ANSYS to determine the maximum deformation, velocities and accelerations of the manipulator; however, their analyses need to be executed with different types of materials. Another study [3] was done using CREO-2 tools to design two types of manipulators: square and circular shapes robotarm. Although the authors in that research analyzed their designed manipulators withreal time boundary conditions using 3 types of materials: steel, al-356 and ARAMID; the rigid dynamic analysis that is useful to calculate object motion was not considered. A 3-DOF revolute manipulator that could perform typical industrial tasks like painting was designed in [4] by using SolidWorks. Aluminum 6061 -T6 was used for robot's construction to decrease the structure weight. The authors in that study used the inverse kinematics to build the joint-angle equations that were fed into an ATMEGA16 microcontroller. However, the static or rigid dynamic analysis was not used to analyze the manipulator performances. Duicu and Popain [5] proposed a simulated trajectory of a five-axis manipulator. The SolidWorks software was used for modeling the manipulator while Matlab and Simulink software was utilized for trajectory simulation. Although the rigid mechanical was designed using the typical Newtonian dynamics of forces and moments, the manipulator's metal was also not considered. Salem in [6] also used Matlab software to design and analyze the mechanical structure. He built two Simulink models; the first was toanalyze the performance of DC-motor system and the second was to examine the performance of overall manipulator scheme. Hiremath, *et al.* [7] designed and analyzed the performance of 2-DOF manipulator made of composite material (graphite/epoxy) using ANSYS software. The results of static and dynamic tests demonstrated that the composite material manipulator has high bending stress and it was lighter and faster than aluminumarm.Abedi in [8] proposed dynamic modeling of two-link robot arm. His simulation study presented the dynamic behavior of flexible manipulator, in addition to the deformation and displacements of links. Lee in [9] developed a SCARA robot using composite material (graphite/epoxy). The author showed that the composite manipulator had static deflection, vibration and damping ratio superior compared to aluminumarm.

The main objective of this paper is to design and analyze the articulated manipulator performance using CAD-tool (CREO-2) and ANSYS software.Three materials (Steel, En-9, and Al-7075) are employed to determine deformation, stress, shear stress and safety factor values. The designed model is also tested with the dynamic analysis that calculates the deformation, velocity and acceleration. This paper firstly describes the fundamental information of the methodology and material selection. This is followed by explaining the procedure used to create the robot arm by CREO-2 software. Then the static and dynamic analysis of the manipulator performance is presented. Finally the work results are concluded and discussed briefly.

## 2. Methodology and Material Selection

In this researcha 3-arm 6-DOFrobot that has steel as existing materialwas chosen. In order to acquire more accuracy and efficiency two materials (En-9 and Al-7075) were used. The real-time boundary conditionswere applied to calculate results like deformation, stress, shear stress and safety factor values. Generally it is known that the robot arm moves from one direction to othersand therefore the dynamic results of movement has to be calculated. This is done by using rigid dynamic analysis to calculate velocity and acceleration of the designed manipulator. From the entire analyses onecan say which metal is the best for this robotarm.

## 3. CREO-2

CREO-2 is a cadtool which is useful to create 3-d objects. The working principle of the robot arm is shown by using this CAD tool. It means that by using this tool it can run and simulate the transition of object from one place to another. Then this model can be imported into CAE-tool to calculate the testingresults. To create the 3-arm robot the following steps is employed (see Figures 1 and 2)

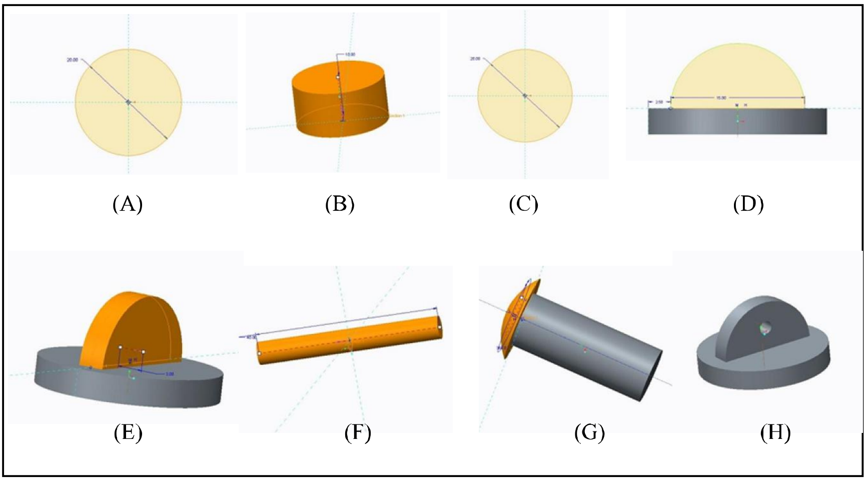



Fig. 1: Steps of creating the 3-arm robot A) Base diameter, B) Base extrude length, C) Top arm diameter, D) Top arm connector, E) Top arm extrude length, F) Circular arm length, G) Screw, and H) Top arm complete model

(A) (B)

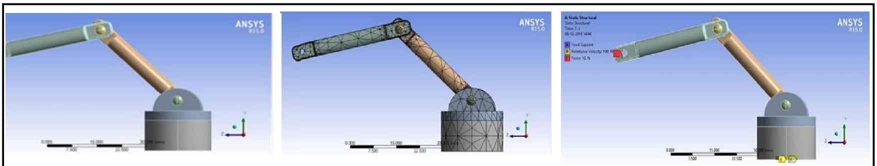
Fig.2: CREO-2 assembly model A) Assembly model and B) Exploded view

## 4. Analysis, Results and Discussion

The designed robot model should be imported into CAE-tool that is ANSYS workbench in order to analyze and evaluate the manipulator performances within static and dynamic loading conditions (see Figure 3). As mentioned before three different materials are used and those are steel, En-9, and Al-7075. Table 1 presents the physical properties of those materials.

Table 1:Physical properties of Steel, En-9, and Al-7075

| | Steel | En-9 | Al-7075 |
|---|---|---|---|
| Young modulus(Pa) | 200e9 | 210e9 | 71e9 |
| Poisson's ratio | 0.29 | 0.30 | 0.33 |
| Density(kg/m$^3$) | 7850 | 7770 | 2883.3 |
| Yield strength(MPa) | 200e6 | 355e6 | 503e6 |




(A) (B) (C)

Fig.3: A) Model imported fromCREO-2, B) Meshing, and C) Boundary conditions

Figure 3Cis showing that how the boundary conditions that is the rotational velocity and force were applied. The rotational velocity is 100R.P.M for first joint (waist or base joint) and the applied force is 10N on third arm.

## 4.1 Static Analysis Results

Figures 4 to 6 show the static analysis results of the deformation, stress, shear stress, and safety factor for chosen materials.

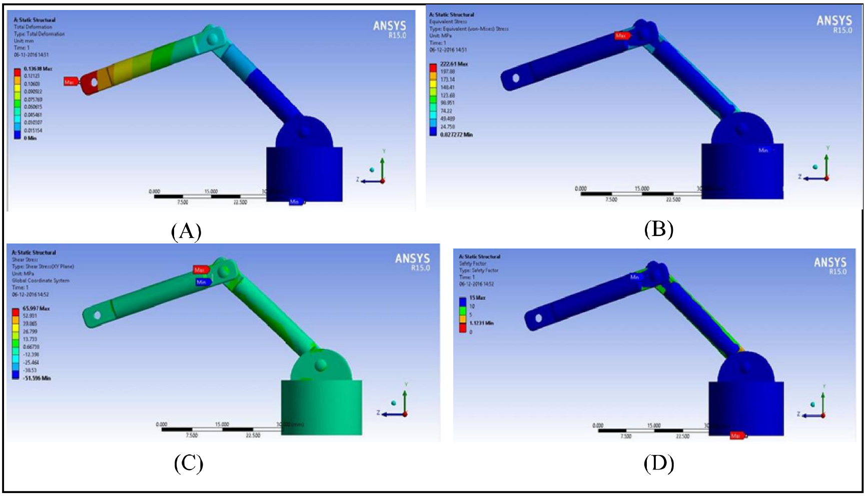



Fig.4: Steel material A) Deformation, B) Stress, C) Shear stress, D) Safety factor

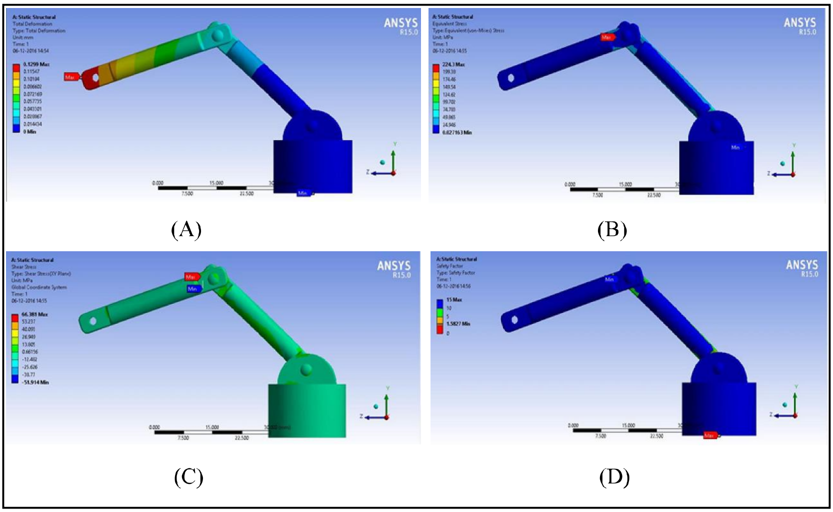



Fig.5: En9 material A) Deformation, B) Stress, C) Shear stress, and D)Safety factor

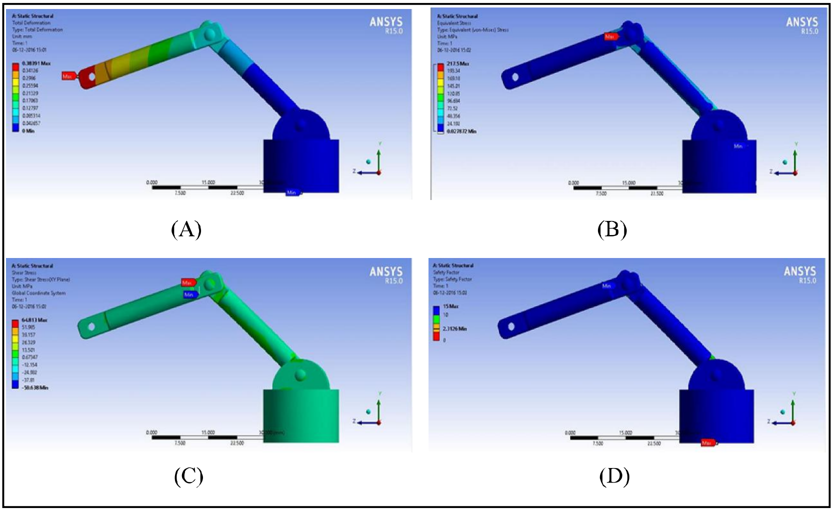



Fig.6: Al-7075 A) Deformation, B) Stress, C) Shear stress, and D) Safety factor

Table 2 shows that results of deformation, stress, shear stress and safety factor values for selected materials. It is concluded that Al-7075 has less stress and high strength compared to other two materials.

Table 2: The static results

| | Deformation(mm) | Stress(MPa) | Shears tress(MPa) | Safety factor |
|---|---|---|---|---|
| Steel | 0.13638 | 222.61 | 65.997 | 1.2131 |
| En-9 | 0.1299 | 224.3 | 66.381 | 1.5827 |
| Al-7075 | 0.38391 | 217.5 | 64.813 | 2.3126 |

Figures 7A to D presents the graphs of results and they show that:

(i) Figure 7A is showing that the deformation is low for steel and high for Al-7075 while En-9 has less deformation compared to other two materials.

(ii) From Figure 7B it can be observed that the stress value of Al-7075 is low compared to steel while En-9 has the highest stress value.

(iii) Figure 7Cshows that the shear stress value of Al-7075 issmallin comparison with steel andEn-9.

(iv) In Figure 7D, it can be realized that the safety factor value of steel isvery low while Al-7075 has a good safety factor value.

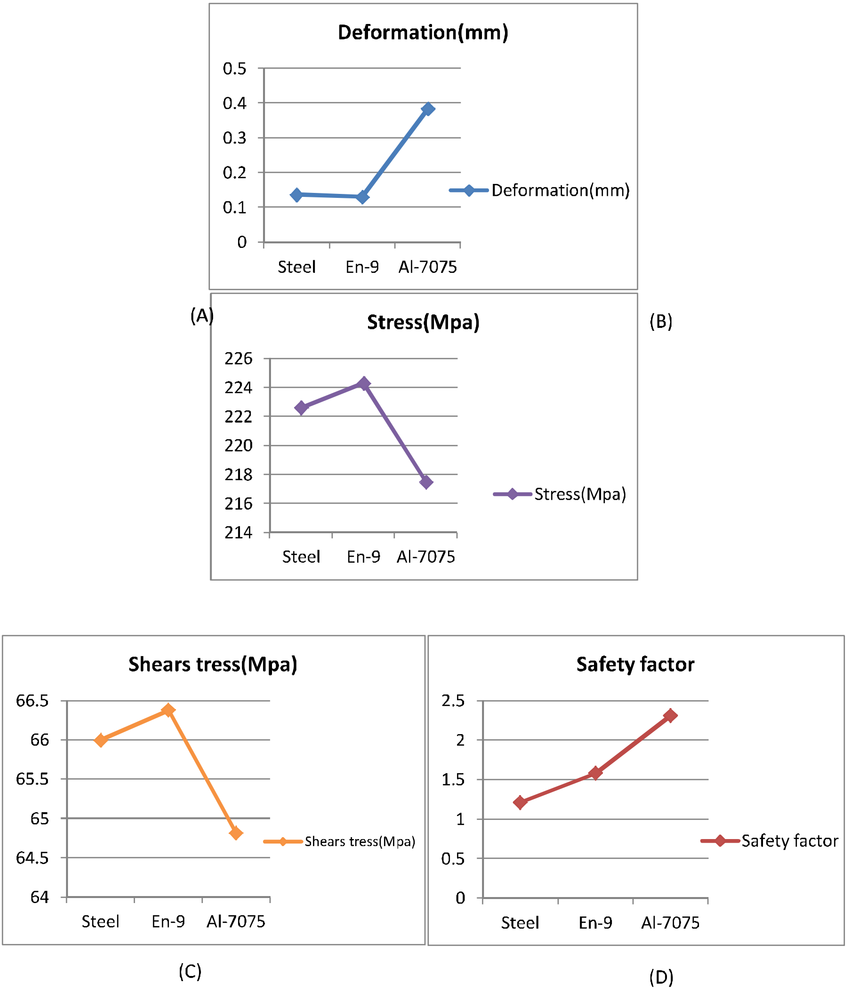



Fig.7: Graphs: (A) Deformation, (B) Tensile stress, (C) Shear stress, and (D) Safety factor

### 4.2 Dynamic Analysis Results

Dynamic analysis is useful to calculate object velocity, acceleration and deformation values by applying rotational velocity. Figures 8 to 10 show the rigid dynamic results of the three materials.

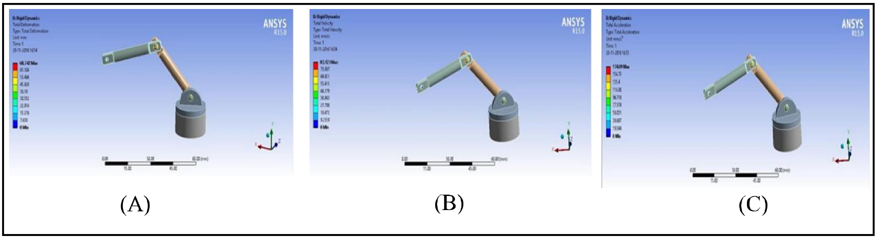



Fig.8: Steel A) Deformation, B) Velocity, and C) Acceleration

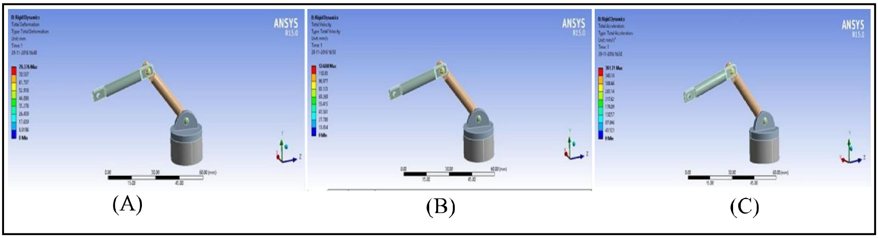



Fig.9: En-9 A) Deformation, B) Velocity, and C) Acceleration

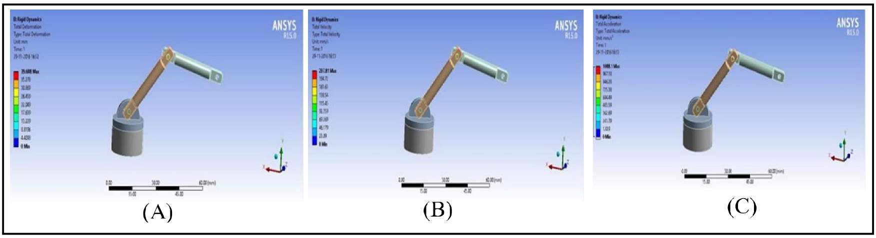



Fig.10: Al-7075 A) Deformation, B) Velocity, and C) Acceleration

Table 3 shows that results of deformation, velocity, acceleration and weight of selected materials. It is concluded that Al-7075 has the highest velocity while steel has the lowest velocity due to their weights. The results also demonstrate that Al-7075 has the lowest weight and good strength.

Table 3: the dynamic results

| | Deformation (mm) | Velocity (mm/s) | Acceleration ($mm/s^2$) | Weight(kg) |
|---|---|---|---|---|
| Steel | 68.742 | 83.123 | 174.09 | 4.0945 |
| En-9 | 79.376 | 124.68 | 391.71 | 3.3927 |
| Al-7075 | 39.688 | 207.81 | 1088.8 | 0.80326 |

Figures 11A to D presents the graphs of the dynamic results and they show that:

(i) The deformation is the highest for En9 manipulator and the lowest for Al-7075 as shown in Figure 11A.
(ii) The velocity is the lowest for steeland the highest for Al-7075manipulator(see Figure 11B).
(iii) The acceleration of the robot arm is low for steel in comparison with Al-7075 and En9 as shown inFigure 11C.
(iv) The Al-7075 robot arm has the smallest weight while the steel arm has the highest weight (see Figure 11D).

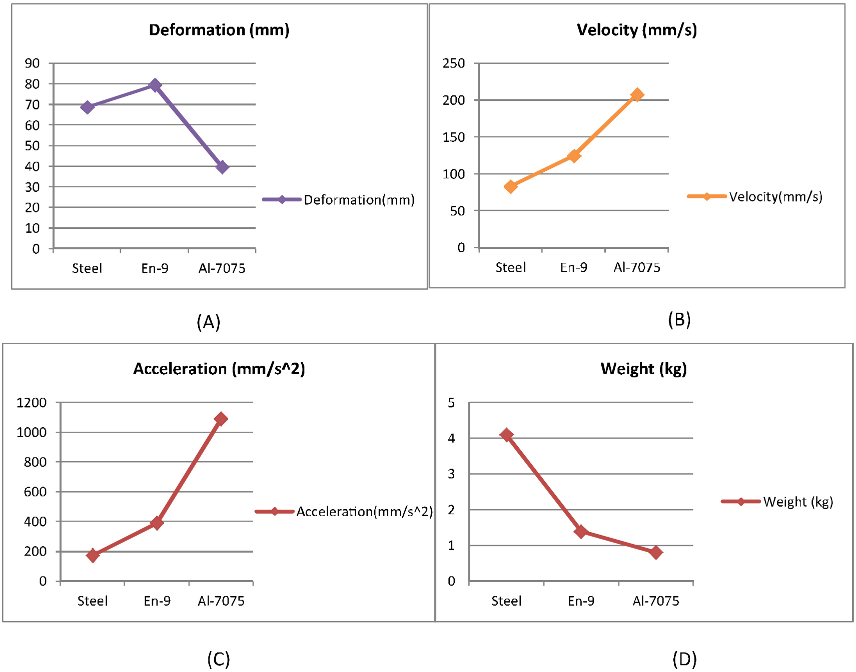



Fig.11: graphs (A) Deformation, (B) velocity, (C) Acceleration, and (D) Weight

## 5. Conclusion

In this research the3-arm 6-DOF elbow robot was designed by using CAD-tool (CREO-2), and then it is imported into CAE-tool (ANSYS workbench). It is then analyzed with static boundary conditions using three different materials (steel, En-9, and Al-7075) to demonstrate results like deformation, stress, shear stress, and safety factor values. However, the robot motion must be considered therefore the dynamic results like velocity, acceleration and deformation for the same materialsare analyzed. It can be concluded that

- The lowestdeformations are occurred within steel and En-9 links comparedto Al-7075 link; however, the safety factor is the highest within Al-7075 link.
- By changing material from steel to En-9 the weight of links is reduced up to 17% but the overall stress increases 2Mpa.
- By using Al-7075 the deformation is increasing 0.2mm extra compared to steel but the overall stress is reduced up to 5Mpa.
- By using Al-7075 the links' weight is reduced nearly 80% compared to steel.
- The dynamic analysis is also showing that Al-7075 has good results and it has high velocity value in comparison with other two materials.
- It can be concluded that al-7075 has extremely good strength to weight ratio compared to other two materials.

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