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Computerised Design Approach to a Sub-Press Mould for Composite Materials Manufacture

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Abstract. This paper focuses on the design of a sub-press mould mounted on a 100-Tonne hydraulic press during compression moulding of composite materials manufacturing process. The sub-press consisting of platens, punch and mould, and guide columns were designed using Microsoft Visual Basic software to minimize time wastages in trail-and-error procedures and mould modifications resulting after the mould is manufactured. Graphical representations of variables which were used in the design such as: platen thickness, guide pin dimensions, clamping force, heat supply, heat losses, and heating element were obtained. The program developed was tested on a solved example in a standard textbook and the result obtained compared well with the result in the book.

Introduction

Compression moulding is one of the widely used methods in the manufacture of composite materials, which involves introducing a specific charge quantity of thermosetting plastic raw materials into the cavity of a pre-heated die. The charge could either be in granular or palletized pre-form condition. A die plunger (punch) is pressed from above into die cavity to mould the charge into shape under pressure and heat until full thermo-chemical cure is accomplished. Thereafter, the product is removed from the mould and a new cycle can be commenced immediately [1].

The compression moulding process is widely used in automotive, aerospace, sporting goods, and electronics industries to produce parts that are large, thin, lightweight and strong, and stiff [2]. Composite materials are formed as a combination of two or more different material components usually consisting of a reinforcing agent and a resin (binder). As reported [3], the use of composite has grown significantly over the last two decades. This is consequent upon the demand for materials with high strength-to-weight ratio, especially in automobile towards fuel economy as the fuel price fluctuates in the global market.

There is also the growing interest in the use of renewable, recyclable and reusable materials in the 21st century. Especially biomass based resources (which are a good source of biofibres) because of environmental and economic considerations towards sustainable global economy. According to Masayuki and Dauda [4], an estimate of more than 2 billion metric tons of agro-based raw materials from crop residues are potentially available. This, therefore, suggests that as some of the reinforcing fibres used in composite materials are of plant origin, there is a tremendous source of raw materials available for developing new value-added materials. In view of the above, an understanding of both the materials and the manufacturing processes involved are critical for optimal utilization of the resources. There are different methods that are used for the fabrication of composite materials. In this case, the compression moulding technique is being considered because of its simplicity and importance. There is scarce information on computer based design approach to compression moulding. According to Akpobi [5], there are very few documented works in the area of software development for design of machine elements. Therefore, the objective of this work is to develop a computerised design approach to a sub-press mould for a composite materials manufacture. Furthermore, with the use of computer aided design, tedious calculations encountered in designs are simplified [6], which would lead to decrease in product costs, improved quality, reduce cycle time and creates better chances for profit making. In particular, by reducing the machine size and weight through a good design work, the cost of the machine is substantially reduced due to lower material utilization and reduced actuator requirement [7].

Methodology

In the development of the software, an algorithm was first developed. Subsequently, formulas were used in determining the design parameters, which were programmed with a user friendly Microsoft Visual Basic programming Language [8,9] in order to build an appropriate graphic interface.

Algorithm of Software: The algorithm considered for the mould design was as follows: thickness of platen, guide pin diameter, spring design, mould, heat requirement, heat losses, useful heat, and heating element length and diameter.

Sub-Press Structure

Platen Design: The sub-press as shown in Fig.1 is principally made up of the top and bottom platens, punch and mould, and the frame supports. It is separated by poor conducting material, that is, high-density plywood from getting direct contact with the hydraulic press table and piston.

The thickness of the platen is designed to withstand the clamping force from the hydraulic press that is experienced during compression moulding of composite materials. During the moulding operation, the platens and punch are subjected to compressive stress. Based on the work of Grashof and Bach as reported [10], the thickness (t) of a rectangular plate subjected to a compressive force (Fa) uniformly distributed over the total area is given by the following formula:

$$t = abk_1\sqrt{\frac{F_a}{\sigma_t\left(a^2+b^2\right)}} \quad (1)$$

where

a = Length of the plate (m)

b = Width of the plate (m)

K_1 = Coefficient of mild steel rectangular plate

F_a = Compressive force N/m^2

σ_t = Allowable design stress on mild steel (N/m^2)

Considering the safety factor (Fs_1), the actual thickness is given thus:

$$t_a = t \times Fs_1 \quad (2)$$

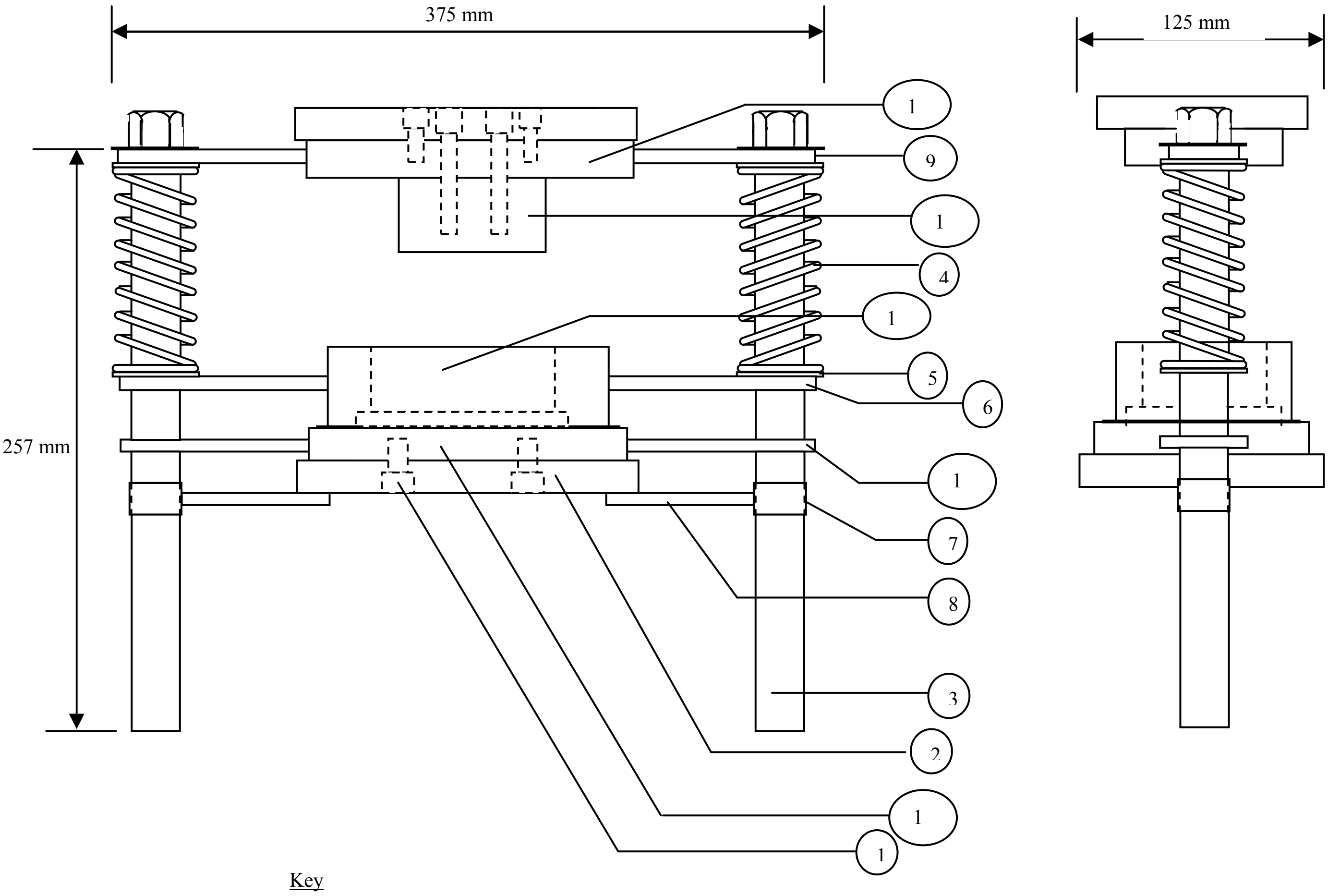
Hence, the mass (M) is given ass;

$$M = \rho_1 \times a \times b \times t_a \quad (3)$$

ρ_1 = density kg/m^2

Therefore, the weight of platen is: $W_t = M \times 9.81$ (4)

Similarly, the bottom platen has the same size and weight. The thickness of the mould was chosen as 35mm so that the cavity could accommodate the charge enough to produce a component.



Key

1. M10 Bolt	8. Arm Rest
2. Wood Insulator	9. Top Platen arm
3. Guide Pillar arm	10. Bottom Platen
4. Compression Spring	11. Top Platen
5. Washer	12. Bottom Platen
6. Mould arm	13. Punch
7. Bushing	14. Mould Cavity

Fig.1 Sub-press mould

Guide Pin Design: Although, the top and bottom platens and the mould are aligned using a guide pillar passing through the armrest (bracket), a guide pin is also provided to ensure that the punch goes into the mould cavity during its operation. Hence, it is important to design for the guide pin so that it does not fail under compressive load. Given that a working load (W_L) and press piston diameter, the critical load (W_{cr}) to avoid buckling is given by the formula [10]:

$$W_{cr} = W_p \times Fs_2 \qquad (5)$$

Where: Fs_2 = factor safety
But the load acting on the platen W_p is:

$$W_p = \frac{a \times b \times W_l \times 4}{\pi d_{pp}^2} \qquad (6)$$

Where d_{pp} = the diameter of press piston
Since the guide pin is similar to a push rod; therefore the equivalent length of the guide pin is equal to the actual length of the guide pin. Using Euler's equation[10]:

$$W_{cr} = \frac{\pi^3 E d_p^4}{64 L^2} \qquad (7)$$

where
L = Length of guide pin

d_p = diameter of guide pin
E = Modulus of elasticity N/mm^2

From equation (7), the guide pin diameter for the sub-press was obtained as:

$$d_p = \sqrt[4]{\frac{64 W_{cr} L^2}{\pi^3 E}} \qquad (8)$$

Spring design: The choice of two compression springs in order to support the top platen when the sub-press is not engaged was based on their deflection (δ) thus [9]:

$$\delta = \frac{8 W_t D^3 n}{G d_{sw}^4} \le P_s \qquad (9)$$

where
P = Pitch of spring mm
n = Number of turns
d_{sw} = Diameter of wire mm
D = Outside diameter of spring mm
W_t = Weight of top platen N
G = Modulus of rigidity N/m m^2

Heat Analysis for Mould: After the components design of the sub-press, it is important to determine the power input required to maintain the operating temperature of the mould to aid the curing of the charge in the mould.

The amount of heat (Q_1) that is needed to heat the platens and mould is as follows [11]:

$$Q_1 = M_1 \times c \times (T_w - T_\infty) \qquad (10)$$

where
c = Specific heat capacity J /kg K
Tw = Temperature of the plate or mould ^{o}C
T∞ = Temperature of the surrounding.
M_1 = Total mass of platens and mould

Generally, there are three modes by which heat can be transferred. And it is important to consider these heat losses from the energy generated (Q_1). They are: heat loss by convection Q_{conv} due to the movement of the fluid on the surface of the hot mould as a result of differences in densities because of the temperature differences as in natural or free convection. Q_{conv} is given as follows [9]:

$$Q_{cov} = h_c \times A_T (T_w - T_\infty) \qquad (11)$$

where
h_c = Convective heat transfer coefficient W/ m^2 C
A_T = Surface area m^2

Heat loss by conduction Q_{cond}, which occurs through the top and bottom platens. The platens are separated from the hydraulic press through a high-density wood, which serves as an insulator. Q_{cond} is given by:

$$Q_{cond} = \frac{k A_T \left[(T_w + 273) - (T_\infty + 273)\right]}{t_i} \qquad (12)$$

where
k = Thermal conductivity W/mK
t_i = Thickness of insulator

Heat loss through radiation Q_{rad} since higher temperature bodies emit more electromagnetic wave compared to cold bodies. This is as follows [11]:

$$Q_{rad} = F_e \sigma F_g A_T \left[(T_w + 273)^4 - (T_\infty + 273)^4\right] \qquad (13)$$

Where
F_e =Surface emissivity of steel = 0.8

F_g =View factor (negligible)
σ = Stefan – Boltzmann constant W/ m^2 K^4
Hence the total heat losses Q_t is:

$$Q_t = Q_{rad} + Q_{cond} + Q_{conv} \quad (14)$$

Therefore, the total heat requirement = useful energy for heating the mould + heat losses (Q_t). Assuming the holding time (T_h) per operation is given in minutes, the power required P (Watts) is given thus:

$$P = \frac{Q_1}{T_h \times 60} + Q_t \quad (15)$$

Design of Heating Element: Usually, heating elements are made from circular cross-section or rectangular conducting ribbons. For a steady-state condition, a heating element dissipates as much heat from its surface as it receives the power from electric supply. Hence, if P is the power input and H is the heat dissipated by radiation, then P = H under steady-state conditions. According to Stefan's Law of radiation, heat radiates by a hot body given as follows [12]:

$$H = 5.72 e_m k_r \left\{ \left(\frac{T_1}{100} \right)^4 - \left(\frac{T_w + 273}{100} \right)^4 \right\} \quad (16)$$

K_r = Radiating efficiency
e_m = Emmisivity of heating element
Diameter of heating (d_h) wire is given by:

$$d_w = \sqrt[3]{\frac{\rho P^2}{2.4649 H v^2}} \quad (17)$$

where
ρ = Resistivity of material Ωm
V = Voltage
And the length of heating wire is obtained by using the formula:

$$l = \sqrt{\frac{d_w v^2}{4 \rho H}} \quad (18)$$

Results and Discussion

This work employed the use of a computer program using visual basic programming language and ms excel. The moulding pressure (clamping load) is assigned as input in the program. Subsequently, the thickness of platen, guide pin diameter, spring design, mould, heat requirement, heat losses, useful heat, and heating element length and its diameter are computed within a splint of a second. The program further analyses the parameters and presents it in a graphical form for easy interpretation and possible forecasting of an outcome. This has not only reduced the time involved in computing but also can efficiently help the user to understand the implication on the values of parameters selected for particular design. Although, outside the scope of this work, the program could also be used in the optimisation of the parameters.

The following example was used in test running the software: *Example [12]*
A resistance oven employing nichrome wire is to be operated from 220V single-phase supply and is to be rated at 16kW. If the temperature of the element is to be limited to 1170°C and average temperature of the charge is 500°C, find the diameter and length of the element wire. Radiating efficiency = 0.57, Emmisivity = 0.9, specific resistance of nichrome = 109 x 10^{-8} ohm-m.

Solution: By using equations 17 and 18 the length (l) and the diameter of the element wire were obtained as 16.05m and 2.716mm respectively by using the software.

Further Test Run: By varying the clamping load as follows; 2, 4, 6, 8 and 10 tons and maintaining the theoretical mould temperature at 160^{o}C, the following results were obtained:

Figure 2 shows the effect of varying the clamping pressure on the size of guide pin diameter for the mould set. From the figure, it is observed that as the clamping pressure required to compress a charge increases, there is a corresponding need to increase the guide pin diameter that can withstand possible compressive load during the initial alignment of the mould set. Similarly, there is also a corresponding increase in platen thickness when the clamping force is increased (figure not shown).

It is known that in compression moulding exercise, there is simultaneous application of pressure and heat on the charge in the mould. Owing to heat losses which are mainly through conduction, convection and radiation, not all the heat used in heating the platens and mould are utilized. As the heat generated increased, the amount of heat losses also increased correspondingly. The heat energy was provided through the heating element. It was observed that as the power requirement increased, there was a corresponding increase in the length of the heating element as illustrated in figure 3. The quantity of heat losses were as follows in the descending order: conduction, radiation, and convection as shown in Fig.4. When the dimensions of the platen and mould were increased, it was observed that the quantity of heat required for the charge to attain its curing temperature also increased.

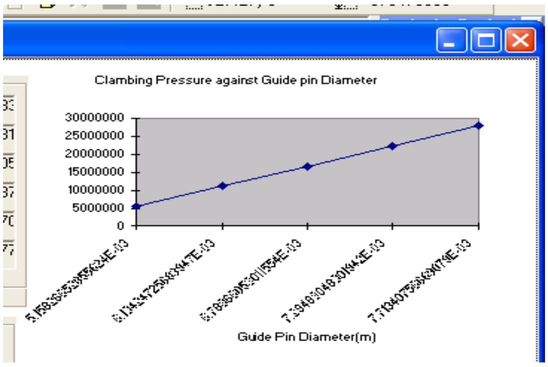


Fig. 2: Clamping pressure and guide pin diameter

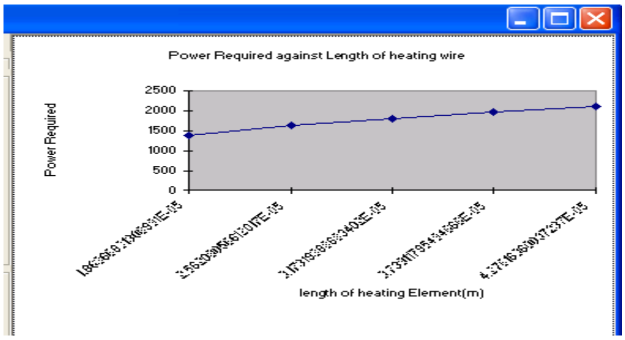


Fig. 3: Power required and length of heating wire

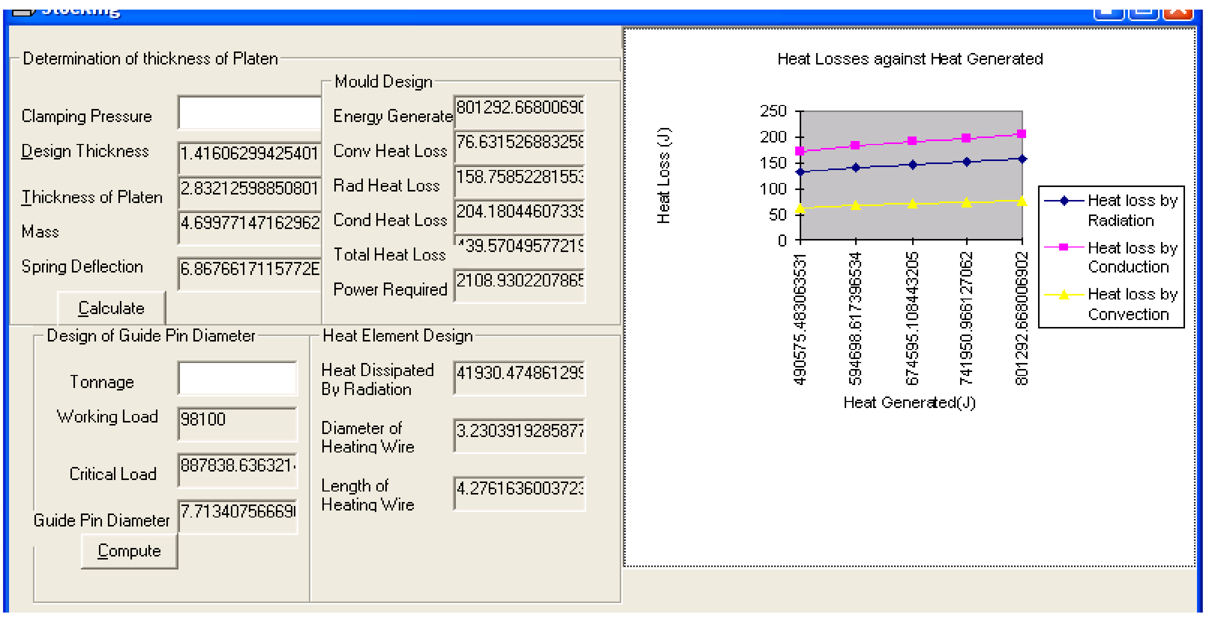


Fig. 4: Heat losses and heat generated

Conclusion and Recommendations

The software developed has demonstrated that tedious design calculations encountered in mould design could be made much easier and more efficient. It has also shown graphically the effect of varying the design parameters. It is recommended that instrumentation and the use of programmable logic controller will be incorporated in future work.

For improved efficiency, speed, accuracy, productivity, repeatability, and quality of local products, especially in the developing countries such as Nigeria, it is recommended that the small and medium scale enterprises (SMEs) should embrace the use of computerised design approach to machine components and systems so that their products could compete more favourably with similar products in the global market.

References

[1] A.O.A Ibhadode, Introduction to manufacturing Technology Ambik press Benin City 2001.

[2] A. Rios, B. Davis and P. Gramann, Computer Aided Engineering in Compression Moulding. The Madison Group: Polymer Processing Research Corporation http: //www.madisongroup.com/publications/cae.pdf (accessed march,2008)

[3] A.S. Ahmed, Materials Selection for Process Equipment in Basic Concepts in Process Equipment and Plant design, A. Kuye and D.B. Ayo (Eds) A Publication of: Raw Materials Research & Development Council, Abuja, Nigeria (2007) 107 – 132.

[4] M. Yoshiba and M. Dauda, Rationalization of Materials and Thermal Recovery System for Non-Woody Agricultural Wastes, Transactions of the Materials Research Society of Japan 25 (3) (2000)685-688.
[5] J.A.Akpobi, Computer-Aided Design of Clutches; NJEM, Vol. 8, No.3 (2007)19-31.
[6] J.A.Akpobi and P. Oboh, Internal Combustion Engines; A Computerized Design Approach, Advance Material Research, Trans Tech Publications, Switzerland, Vols. 18-19 (2007)423-433.
[7] N.Doshi and D. Kazmer, Layout Design of a Platen less Molding Machine, ANTEC, PP 3539 – 3543 http://kazmer.uml.edu/staff/archieve/2003ANTEC_platenless(accessed March 2008)
[8] S.J. Podlin and P. Palmer, Hands on Visual Basic 6,Tech Publications Pte Ltd., Singapore.
[9] B. Siler and J.Spotts, Using Visual Basic 6(special edition),Macmillan Computer Publishing, Indianapolis,USA.
[10] R.S. Khurmi and J.K. Gupta, Machine Design, Prentice- Hall, India, 2003.
[11] J.P. Holman, Heat Transfer, 8th Edition, McGraw-Hill Co., New York, 1997.
[12] B.L. Theraja and A.K.Theraja, A Textbook of Electrical Technology, S.Chand & Company Ltd. New Delhi, 2008.

NOMENCLATURE

A =Surface area (m^2)
a =Length of the plate (m)
b. =Width of the plate (m)
C =Specific heat capacity (J /kg K)
D =Outside diameter of spring (mm)
d_h =Diameter of heating wire(m)
d_p =diameter of guide pin(m)
d_{pp} =diameter of press piston(m)
dsw =Diameter of wire mm(m)
E =Modulus of elasticity (N/m^2)
e_m =Emmisivity of heating element
F_e =Surface emissivity of steel = 0.8
F_g =View factor (negligible)
F_a =Compressive force (N/m^2)
G =Modulus of rigidity N/m^2)
H =Heat radiation or dissipated (J)
h_c =Convective heat transfer coeff (W/m^2 C)
I =Moment of intertia (m^4)
k =Thermal conductivity (W/mK)
K_1 =Coefficient of mild steel rectangular plate
K_r =Radiating efficiency
L =Length of guide pin(m)
l =Length of heating wire(m)
M =Mass of platen (kg)
M_1 =Total mass of platens and mould (kg)
n =Number of turns
P =Power input (W)
Ps =Pitch of spring (m)
Q_1 =Energy needed to heat the platens and mould(J)
Q_{cond} =Heat loss by conduction
Q_{conv} =Heat loss by convection (W)
Q_{rad} =Heat loss by radiation (W)
t. =Platen thickness (m)
t_a =actual thickness of Platen (m)
Th =Holding time (minutes)
$T\omega$ =Temperature of the plate or mould (^oC)
$T\infty$ =Temperature of the fluid or air(^oC)
V =Voltage (V)
W_l =Working load (N)
Wt =Weight of top platen (N)
W_{cr} =Buckling load (N)
Wp =Load acting on platen (N)
σ_t =Allowable design stress on mild steel (N/ m^2)
ρ =Resistivity of material (Ωm)
ρ_1 =density (kg/ m^2)
δ =Deflection of the spring (m)
σ =Stefan- Boltzmann constant ($W/ m^2 K^4$)

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