

The Effect of Mould's Temperature variation on Compressive and Fatigue Properties of Casting Aluminum Alloy

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ABSTRACT— *The effect of the mould's temperature variation on compressive and fatigue properties of a cast Aluminum alloy is explored. The mould pre-heat from the range of 30°C to 200°C that controlled with the aid of the electric oven and the temperature of the mould monitored with the bimetallic galvanometer. The fatigue and compressive properties of the cast Aluminum alloy were experimentally investigated and presented. The results show that the increase in mould temperature was found to increase the true compressive strain and number of cycles to failure (a measure fatigue life). However, stress compressive strength and fatigue limit of the specimen were found decrease with increase in mould temperature. These variation shows that the mechanical properties of cast aluminum alloy can be controlled to suit particular application by varying the sand mould temperature.*

Keywords— Mould, barreling, compressive, fatigue, true strain

1. INTRODUCTION

Cast aluminum alloys are one of the most versatile of engineering material in usage especially in the automotive applications. A deep understanding of how their processing affects their mechanical properties will be of enormous advantage to the designer to ensure that the casting will achieve the intended properties during application [1,2,3]. Sand mould preheat is the process of increasing the ambient temperature of the mould to a given temperature in order to influence the properties of the materials cast in it [4,5,6]. Rate of heat transfer between the mould and solidifying casting is crucial to the quality of cast produced [7]. The increase of the temperature of the mould during preheat is the process of applying heat to the mould either through an oven or a furnace before it is used. Mould preheat affects the thermal gradient and hence the cooling rate of the solidified metal in the mould. The lower the mould preheat the higher the thermal gradient and the cooling rate, hence mechanical properties of the cast metal will be affected by mould preheat [8,9,10]. These mechanical properties includes compressive and fatigue strengths. The compressive properties are the characteristics of a material that is subjected to compression. Unlike the tensile test, the compression test of a material is affected by barrelling which is the bulging out of the edges of the specimen. Barrelling effect has to be accounted for when evaluating the stresses and strains in compression test [11,12]. The fatigue failure occurs in a material when it is subjected to a repetitive dynamic or fluctuating stress or load much lower than that required to cause fracture on a single application of load. Load, which can cause fatigue failure apart from axial, can be shear or bending. Fatigue failure is of great importance as it is well attested by the large percentage of failure in machine elements. From estimate made, up to 80-90% of failures in machine components are as a result of fatigue failure [13,14]. Other factors influencing the mechanical properties are the specific heat capacity of the sand, and its thermal conductivity/thermal diffusivity, grain size and porosity of sand [7,14,15].

Solidification of the molten metal takes place inside the mould. According to Khanna [16], the mechanism of solidification and its control for obtaining the castings are the major problems of foundry-men. The quality and properties of cast products are greatly influenced by the different processing parameters involved in casting. The parameters are gating system, pouring temperature, mode of solidification, sand mould preheat temperature and shake-out times [17]. A typical molten metal, of the same pouring temperature, poured into respective sand moulds cavities of different pre-heat temperatures will surely experience different cooling and solidification rates due to the various thermal gradients in the cavities. This, of course, shows that sand moulds preheat temperatures will have great influence on the quality and properties of the cast products. In view of this, considerable investigations shall be carried out in this research work on how preheat of the mould before pouring the molten metal into the mould cavity affect the properties of the casting, as this is the one of the parameters to be used to control the mechanical properties of the aluminum alloy.

2. MATERIALS AND SPECIMENS PREPARATION

2.1 Work Materials

Aluminium scraps consisting of automotive parts and electric cables were used as the work materials in this research project work. Plasma Spectrographic analysis was carried out on the specimen to determine chemical

compositions with the aid of Plasma Spectroscopy. Table 1 shows the chemical composition of the materials (cast aluminium alloy) employed in the research.

Table 1: Chemical composition of the cast aluminium alloy

Element	Si	Mg	Cu	Na	Zn	Ti	Fe	Be	Mn	Al
Percentage (%)	14.9	1.93	4.26	0.37	0.35	0.19	0.70	0.02	0.14	77.49

2.2 Mould Preparation and Preheat

The “green” sand mould was prepared with silica sand, coal-dust, clay and starch (organic binder) that were mixed with the right proportion of water. The moulds were enclosed in metal frames called flasks. Smooth mild steel rods of length 150 mm and diameter 15 mm were used as patterns. The bottom flask called drag was filled with the moulding sand that was compacted with the aid of a rammer. The pattern was placed in the drag to create the mould cavity needed for the casting. Five sets of moulds were preheated to 100⁰C in the oven while the remaining five sets of moulds were preheated to 200⁰C simultaneously as the melting of aluminium alloy continued in the furnace.

2.3 Casting and Shake-out of Specimen’s

Melting of aluminium alloy scraps was done in a 10 kg capacity crucible placed inside the furnace. Flux was added at about 650⁰C by covering the surface of the already molten alloy with about 2% by weight of charge covering flux. The five dry sand moulds left as prepared cavity were fed with the molten metal until the spruce was filled up. The drag and cope housing of the dry sand mould was dismantled or shaken-out at 25 minutes after pouring the molten metal into the cavity.

2.4 Specimen’s Preparation

The cast aluminium rods obtained from as-prepared, 100⁰C preheated and 200⁰C preheated moulds were machined to obtain compression and fatigue test specimens according to ASTM standards [18,19]. The compressive specimens were machined to the lengths of 20 mm and of diameter of 7 mm.

2.5 Experimental Compressive Test

Compressive strengths of the machined specimens were determined by using the Tensometer Tensile Testing machine. The load was applied to the specimen on a compression rig and the specimen was compressed till barrelling occurred along the edges of the specimen. After the compression, the final diameter and the final length were measured.

2.6 Experimental Fatigue Test

The fatigue test of aluminium alloy specimens machined into specification was carried out with the aid of Avery Denison Fatigue Testing machine. The specimen undergoes bending over its entire length. Treating this as a sample beam deflecting downward we see upper portion experience tension while the lower portion simultaneously sustains compression, in the longitudinal direction. However since this “beam” is continuously rotating, the materials in the bar experience an alternating stress (i.e. tension – zero – compression – zero – tension etc.). The cycles of stress were applied until the specimen failed, and the numbers of the cycles-to-failure were recorded for the specimens under the same condition of load specification.

3. RESULTS AND DISCUSSION

3.1 Effect of Mould Preheat on Compressive Properties

The variations of axial compressive strength of specimens obtained from different moulds of varied preheat are shown in Table 2. The maximum compressive strengths were indicated on the Tensometer.

Table 2: Variations of axial compressive strength of Specimens obtained from different moulds of varied preheat and shakeout time.

Shakeout-time, t (minutes)	Axial Compressive Strength (Without barrelling factor) $\sigma_a = F_u/A_o$, (MN/m ²)		
	As-Prepared Mould	100 ⁰ C Preheated Mould	200 ⁰ C Preheated Mould
5	150.7	114.3	101.3
10	140.3	101.3	88.4
15	109.1	77.9	75.4
20	82.2	72.8	70.2
25	80.6	49.4	44.2

Where A_o = original area of specimen = $\pi d^2/4$ and original diameter, $d = 7$ mm.

The height and diametral dimensions are shown in Table 3. These values were used to calculate the correction barrelling factor, C for all the respective specimens according to equation (1) below [20, 21]:

$$C = \left\{ \frac{(1-4R)}{d_2} \ln \frac{(1-d_2)}{4R} \right\}^{-1} \quad (1)$$

and the radius of curvature of barrelling, R, is give as:

$$R = h^2 + \frac{(d_2 - d_1)^2}{4(d_2 - d_1)} \quad (2)$$

where h , d_1 and d_2 is the final height, minimum diameter and maximum diameter of the barrelled specimen respectively.

TABLE 3: Variation of height and diametral dimensions of compressive specimens from moulds of varied preheat and shakeout time.

Shakeout Time, t (minutes)	Height and diametral dimensions																	
	As-Prepared Mould						100 ⁰ C Preheated Mould						200 ⁰ C Preheated Mould					
	Diameter (mm)		Height (mm)				Diameter (mm)		Height (mm)				Diameter (mm)		Height (mm)			
d_1	d_2	d_a	h	h _o	d_h	d_1	d_2	d_a	h	h _o	d_h	d_1	d_2	d_a	h	h _o	d_h	
5	7.0	7.40	0.40	20.0	19.09	0.91	7.0	7.50	0.50	20.0	18.25	1.75	7.0	7.65	0.65	20.0	17.50	2.50
10	7.0	7.60	0.60	20.0	18.01	1.99	7.0	7.80	0.80	20.0	17.50	2.50	7.0	7.85	0.85	20.0	16.00	4.00
15	7.0	7.85	0.85	20.0	17.50	2.50	7.0	7.95	0.95	20.0	16.80	3.20	7.0	8.10	1.10	20.0	15.20	4.80
20	7.0	8.05	1.05	20.0	17.00	3.00	7.0	8.15	1.15	20.0	16.02	3.98	7.0	8.35	1.35	20.0	14.80	5.20
25	7.0	8.25	1.25	20.0	16.02	3.98	7.0	8.40	1.40	20.0	15.40	4.60	7.0	8.60	1.60	20.0	14.20	5.80

TABLE 4: Variations of barrelling factor ‘C’ of specimens from Moulds of varied preheat and shakeout times

Shakeout Time, t (minutes)	Barrelling factor, C		
	As-Prepared Mould	At 100 ⁰ C Preheated Mould	At 200 ⁰ C Preheated Mould
5	0.977	1.006	1.009
10	1.011	1.011	1.013
15	1.013	1.014	1.019
20	1.015	1.038	1.028
25	1.022	1.041	1.037

The variations of the barrelling factors of specimens from moulds of varied preheat and shake-out is shown in Table 4. The barrelling factors are multiplied with the corresponding axial compressive strength to generate Figure 1. The figure shows the variations of effective/true compressive strength of the specimens from moulds of varied preheat temperature and shakeout time.

It can be was observed from the figure that increase in mould preheat temperature has a reduction effect on the effective/true compressive strength of the specimens. The effective/true compressive strength of specimen obtained from as-prepared mould decreases from a value of 147.2 MNm⁻² to 115.0 MNm⁻² and 102.2 MNm⁻² when the mould preheat temperature was increased from ambient temperature to 100⁰C and 200⁰C respectively for shakeout time of 5 minutes. This trend is also observed in the other shakeout times.

As it was earlier stated for axial compressive strength, the observed reduction in effective/true compressive strength of the specimen with increase in mould preheat temperature could also be attributed to the increase in heat accumulation in the mould prior to casting which resulted in a reduction thermal gradient consequently resulted in a slower cooling rate which improved the softness/ductility of the cast specimen at the expense of its axial compressive strength.

The reduction in effective/true compressive strength of the specimens with increase in temperature could also be ascribed to the fact that specimen retains more heat in the mould when the shakeout time is elongated. The more the heat retained, the higher the ductility of the specimen and the lower the effective/true compressive strength of the specimen.

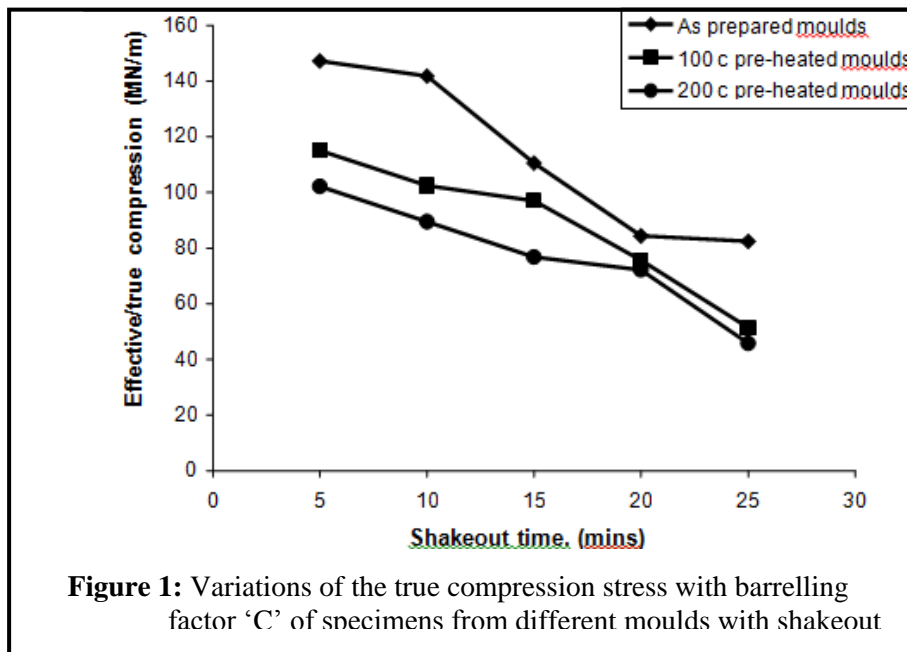


Figure 1: Variations of the true compression stress with barrelling factor 'C' of specimens from different moulds with shakeout

The variations of true compressive strain with mould preheat temperatures are shown in Figure 2. True compressive stain is expressed as [11]:

$$\epsilon = - \ln(h/h_0) \tag{3}$$

where h and h₀ is the final and initial heights of the cylindrical specimen, respectively.

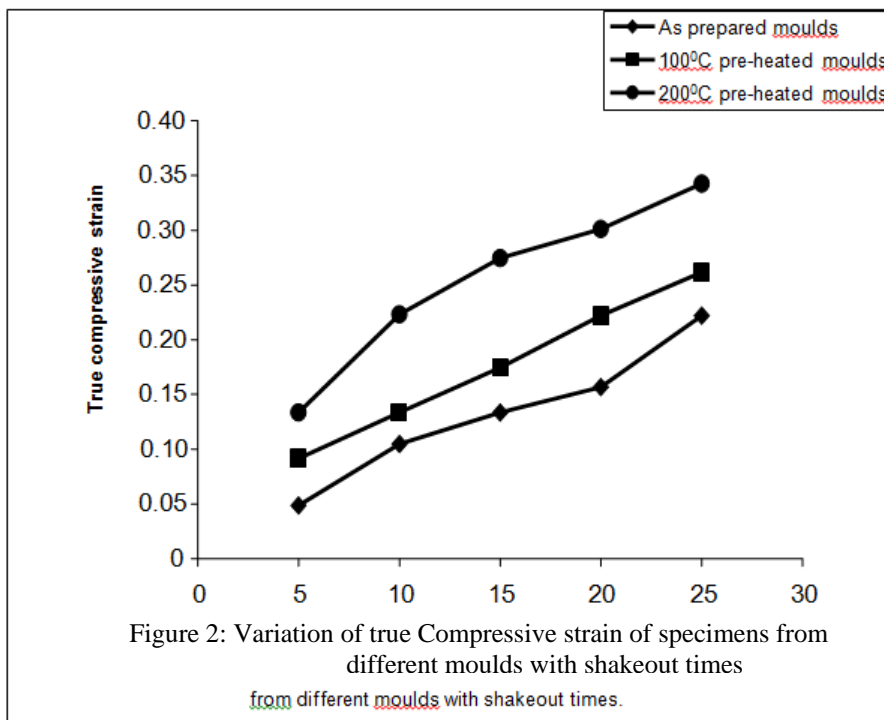
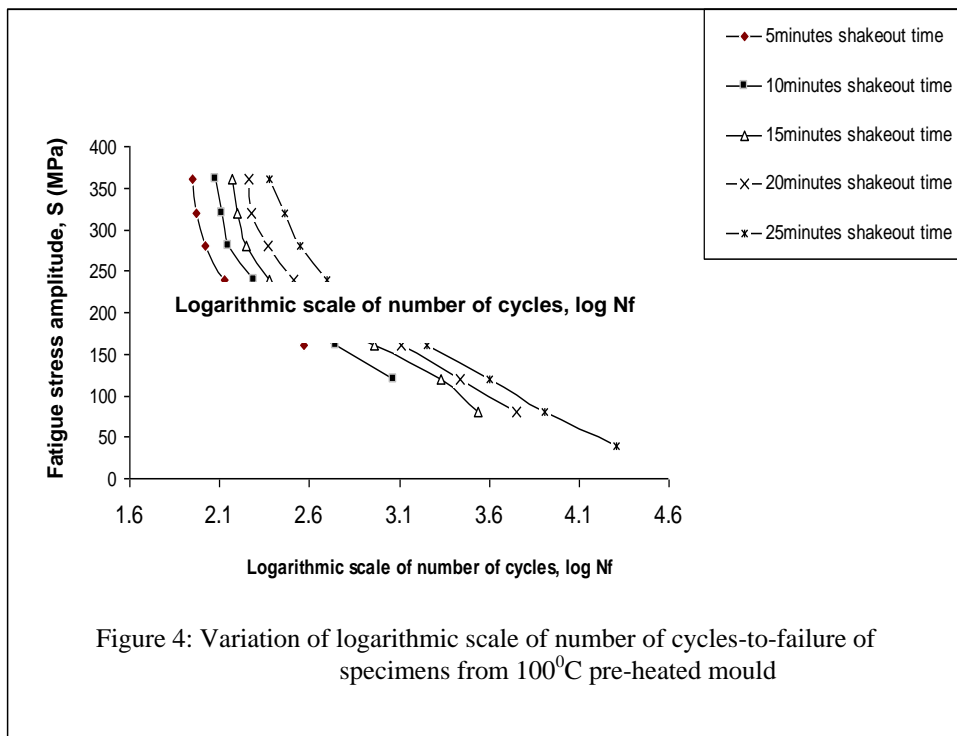
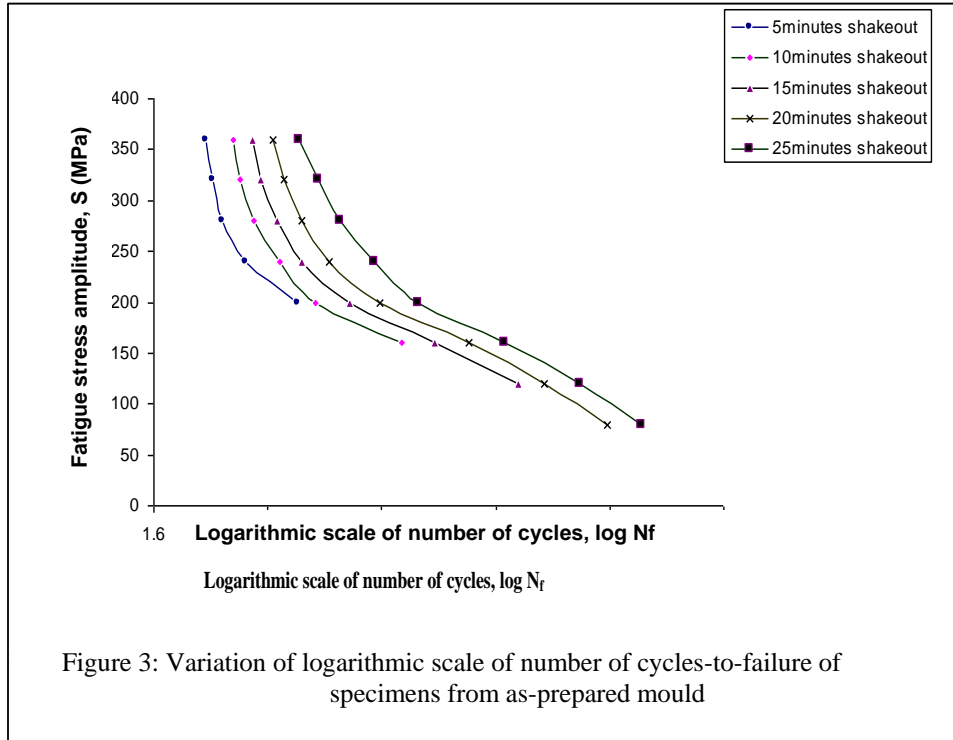


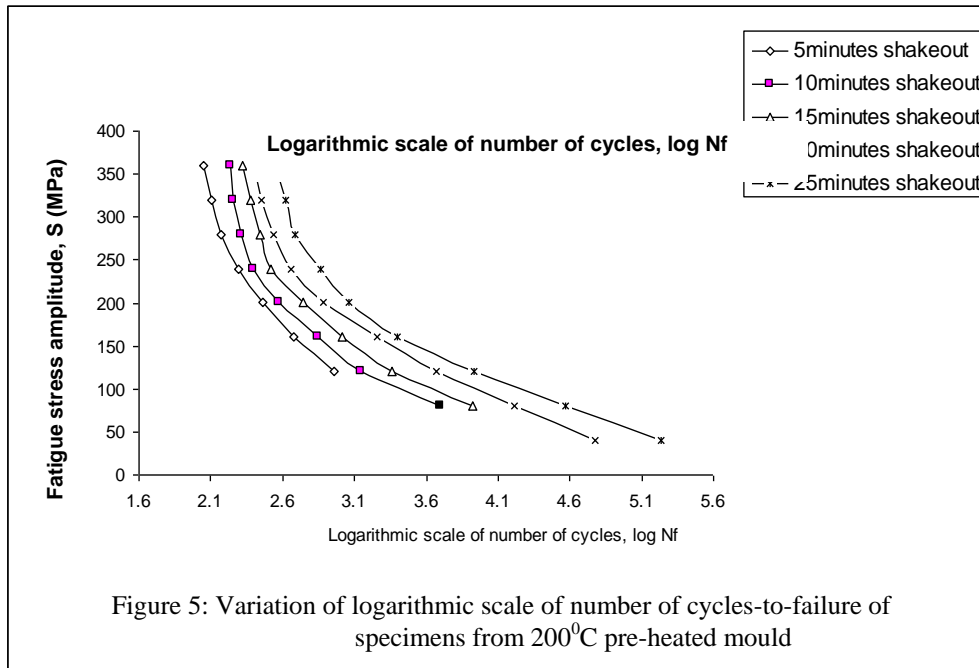
Figure 2: Variation of true Compressive strain of specimens from different moulds with shakeout times

Increases in mould preheat temperature was found to increase the true compressive strain of the specimen. The true compressive stain of specimen obtained from as-prepared mould increased from 0.0466 to 0.0196 and 0.1335 when the as-prepared mould was preheated to 100⁰C and 200⁰C respectively for a shakeout time of 5 minutes. This trend is similarly noted in the other shakeout times.

3.2 3.2 **Effects of Mould Preheat on Fatigue Properties**

The plots of fatigue stress amplitude against the logarithmic scale of number of cycle-to-failure (S-N curves) are shown in Figure 3, 4 and 5. These graphical representations were obtained from the variations of the number of cycles-to-failure (N_F) and logarithmic scale of number of cycles-to-failure ($\log N_F$) of as-prepared, 100⁰C and 200⁰C preheated moulds.





The specimen obtained from as-prepared mould was observed to display highest fatigue stress of 200 MPa with corresponding number of cycles-to-failure of 169 (i.e. $\log N_f = 2.23$). The specimen obtained from 100°C preheated mould exhibited a fatigue limit of 160 MPa with corresponding fatigue life of 372 number of cycles-to-failure (i.e. $\log N_f = 2.57$).

The specimen from 200°C preheated mould, 5 minutes shakeout time, displayed a fatigue stress of 160 MPa and a fatigue life of 912 numbers of cycles-to-failure (i.e. $\log N_f = 2.96$). The trend of variations shows that increase in temperature has a reduction effect on the fatigue stress but an increasing effect on the fatigue life. This observed variations could be attributed to the fact thermal gradient in the mould decreases with increase in preheat temperature. The higher the thermal gradient the faster the cooling rate, consequently, the less ductile the specimen and the shorter the fatigue life displayed.

Hence, the lowest fatigue stress with the highest logarithmic scale of number of cycles ($\log N_f$) displayed by cast specimen from 200°C preheated mould could be attributed to the heat accumulation in the mould due to mould preheat and the lowest thermal gradient resulting in minimum loss of heat when compared with those from 100°C preheated and as prepared mould. As prepared mould experienced highest thermal gradient because of the absence of any previous heating, hence fastest cooling was observed in as-prepared moulds. This trend of variations in fatigue stress and number of cycles-to-failure is observed in all the others shakeout time considered.

4. CONCLUSIONS

In this study, sand moulds temperatures were varied with a view to controlling the mechanical properties of a cast aluminium alloy specimens. Increases in moulds temperature were found to increase the true compressive and number of cycles-to-failure (a measure fatigue life) for this particular cast aluminium alloy. However, axial compressive strength, effective/true compressive strength and fatigue limit of the specimen were found to decrease with increase in mould preheat temperature. This could be attributed to the fact that increase in mould temperature indicates an increased heat accumulation in the mould prior to casting which results in a reduction in thermal gradient during casting and consequently results in a slower cooling rate which improves the softness/ductility at the expenses of strength and hardness.

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