

The Potential of Sisal Fiber as an Additive in Lightweight Foamed Concrete for Thermal Properties Enhancement

Md Azree Othuman Mydin¹

¹ School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
e-mail: azree@usm.my

ABSTRACT

Lightweight foamed concrete (LFC) is extremely permeable, and its thermal properties reduce with rising in the number of voids. In turn, to improve its thermal properties, the solid matrix of LFC can be adjusted by incorporating several natural fibers. The influence of sisal fiber in LFC was not investigated before in the current body of knowledge. Hence, there is some ambiguity considering the mechanism by which and the extent to which the sisal fiber can influence LFC thermal properties. Hence, this study concentrates on distinguishing the potential use of sisal fiber in LFC. The purpose of this research is to determine LFC's thermal characteristics when sisal fiber is added. Casting and testing of densities of 800 kg/m³ and 1600 kg/m³ were done. Various weight fractions were employed pertaining to sisal fiber, i.e., 0.15%, 0.30%, 0.45% and 0.60%. The components of thermal properties, which consist of specific heat, thermal conductivity as well as thermal diffusivity were evaluated. To get comparable results, we fixed the water to cement ratio as 0.45 while keeping constant the cement to sand ratio at 1:1.5. It was seen that optimum results were achieved with the addition of 0.45% of sisal fiber with regard to all the thermal characteristics regarded in this exploration. At 0.45% weight fraction about sisal fiber, maximum compaction was achieved with fibers as well as the cementitious matrix, which ensued in good mix uniformity. Beyond the optimum level pertaining to the presence of sisal fiber, it could be seen that fibers would agglomerate and exhibit non-uniform dispersion, which resulted in a decline with regards to the entire thermal characteristics assessed.

Keywords: foamed concrete; thermal properties, conductivity; diffusivity, specific heat.

INTRODUCTION

The Malaysian construction industry has demonstrated major appreciation with regards to the employment of Lightweight foamed concrete (LFC) for building construction due to its different attributes, such as being easy to fabricate, lightweight, vigorous, and cost-effective [1, 2]. LFC is a lightweight concrete material that contains ordinary Portland cement along with the creation of a homogeneous pore structure by providing air in the form of small bubbles [3, 4]. LFC can be defined as a cement paste wherein air voids would be in the size of 0.1 mm to 1.0 mm that are homogeneously dispersed via a suitable surfactant in either a matrix of aggregate or cement paste or just as cement paste [5, 6]. A broad-scale of LFC can be manufactured with densities in the range of 600 to

1,800 kg/m³ by setting a precise mechanism with regard to the amount of foam and production techniques [7]. The worldwide interest in eco-friendly building materials has propelled a lot of research on green concrete globally [8]. Awareness has been given to areas, such as concrete mix design, mix material sourcing, and concrete structure upkeep [9]. FC properties include low density, high flowability, excellent thermal performance, and good sound absorption [10, 11, 12]. With appropriate control pertaining to the amount of foam, fabrication of an extensive choice of densities could be done in the range of 400 to 1,900 kg/m³ [13, 14]. In addition, LFC is regarded as an economical alternative for yielding large-scale lightweight construction products, like filling grades, partitions, road embankment infill, and structural components, because of its easy-to-use manufacturing method

that encompasses all production stages, i.e., from manufacturing plants to final placement of applications [15, 16, 17]. It is crucial to distinguish the amount of fibers, cement, sand, water, and foaming agent in the mixture [18]. Natural fibers have several advantages over synthetic fibers, including the fact that they are biodegradable, low in density, and are difficult to melt when heated. Natural fibers can be used to reinforce cementitious materials, particularly when developing and fabricating building materials [19, 20]. The latest research work by Raj et al. [21] evaluated the performance about LFC that was reinforced with polyvinyl alcohol fiber and coir fiber. They identified that the performance of LFC reinforced with coir fiber was higher versus the one reinforced with polyvinyl alcohol fiber, which also offered better performance when compared with LFC reinforced with the hybrid composites of both fibers. Othuman Mydin et al. [22] studied the use of coir fiber in LFC and found that the inclusion of coir fiber reduced conductivity and thermal diffusivity but enhanced the specific heat capacity of composites. Comparable research studies were conducted by employing steel fiber. The study on LFC composites showed that there was a rise in their thermal diffusivity and thermal conductivity with an increase in the steel volume fraction versus the control specimen. These two results suggest that the thermal characteristics of LFC are improved with coir plant fiber, while steel fiber results in a reduction in the thermal performance of LFC. From the above review, the effect of sisal fiber presence in LFC for thermal properties improvement is not well explored. Thus, the purpose of this study is to determine the thermal properties of LFC reinforced with sisal fiber. Casting and testing of LFC with densities of 800 kg/m³ and 1600 kg/m³ were done with various

weight fractions pertaining to sisal fiber as well as the evaluation of thermal characteristics.

MIXING AND SAMPLE PREPARATION

There was a total of ten LFC mixes of 800 kg/m³ and 1600 kg/m³ densities were made. The weight fractions of sisal fiber utilized in this study were 0.15%, 0.30%, 0.45% and 0.60%. A control LFC without any inclusion of sisal fiber was also made for comparison reasons. In this study, selection of sisal fiber weight fraction is done in the range of 0.15% to 0.60% since, in the pilot study, during the mixing process, the researcher identified that adding sisal fiber weight fraction of greater than 0.6% resulted in agglomeration as well as non-uniform dispersion pertaining to sisal fiber. A 1:1.5 sand to cement ratio was employed and we kept the water-cement ratio constant at 0.5 with regards to all the mixtures. The mix proportions employed in this investigation are displayed in Table 1.

The employed cement complied with the BS12 Standard. Next, natural fine sand was employed as filler. The fine sand had a maximum width of 2 mm, a passage of 60–90%, and a 600-micron sieve. The sand’s suitability complied with BS822. A protein-based foaming agent was employed as the foaming agent because of its stability and tinner bubbles, which would result in maintaining a tougher bubble binding form versus a synthetic foaming agent. Then, the employed tap water was clear and clean, which was employed for preparing the mortar, the curing work, and mixing the LFC. In this research, 0.45 water to cement ratio was employed to attain reasonable workability by taking into account previous research work. Finally, sisal fiber was employed as fiber, which

Table 1. Mix design proportion

Reference	Dry density (kg/m ³)	Ratio (c:w:s)	Sisal fiber (kg)	Cement (kg)	Sand (kg)	Water (kg)
Control - 800	800	1:1.5:0.5	-	30.25	45.37	13.61
Sisal - 0.15%	800	1:1.5:0.5	0.134	30.25	45.37	13.61
Sisal - 0.30%	800	1:1.5:0.5	0.268	30.25	45.37	13.61
Sisal - 0.45%	800	1:1.5:0.5	0.402	30.25	45.37	13.61
Sisal - 0.60%	800	1:1.5:0.5	0.535	30.25	45.37	13.61
Control - 1600	1600	1:1.5:0.5	-	59.13	88.70	26.61
Sisal - 0.15%	1600	1:1.5:0.5	0.263	59.13	88.70	26.61
Sisal - 0.30%	1600	1:1.5:0.5	0.527	59.13	88.70	26.61
Sisal - 0.45%	1600	1:1.5:0.5	0.790	59.13	88.70	26.61
Sisal - 0.60%	1600	1:1.5:0.5	1.054	59.13	88.70	26.61

was procured freshly from the industrial unit post-processing. The SF was encapsulated by a skin of grease, which would also lead to spoilage and fungus growth. The sisal fiber had to be washed until all grease was removed and then placed under the sun for drying. The chemical composition, mechanical characteristics, and physical characteristics about sisal fiber are displayed in tables 2, 3, and 4, respectively. High cellulose percentage was associated with sisal fiber, which can help considerably when in composite action with the LFC with the cementitious matrix.

METHODOLOGY

The hot disk thermal analyzer by considering the BS22007-2 was used to determine specific heat capacity, thermal diffusivity as well as thermal conductivity during the test. Between the two samples, the employed sensor was sandwiched. The employed sample had a size of 25 x 50 mm and a thickness of 10 mm. All specimens to be evaluated must be kept in a dry state condition. Users need to be set data like probing depth, power, and time until achieving an acceptable constant and allowable rate. The thermal diffusivity, thermal

conductivity, and specific heat of material can be tested via this thermal constant analyzer quickly – all at once – and it also offers direct readings. The specimens pertaining to each test were procured post 28 days of curing the batch mixes by employing carefully cut samples of 40×40×20 mm. Post cutting these samples in pairs, they are sandpapered and smoothed. Two samples pertaining to identical dimensions are first kept in the oven at a temperature of 75±5°C for 72 hours or until constant weight in order to eliminate the moisture from them. Two samples of identical dimensions are used to sandwich a constant thermal analyzer sensor. Figure 1 demonstrates the arrangement of the thermal properties test.

RESULTS AND DISCUSSION

Thermal conductivity

Figure 2 shows the results pertaining to LFC’s thermal conductivity with various weight fractions with regard to sisal fiber. As per this study, involving SF of all weight fractions resulted in enhanced thermal conductivity versus the control specimen, which gave 0.2167 W/mK as thermal conductivity. Adding 0.45% volume fraction of SF gave the best result of thermal conductivity. The recorded thermal conductivity was 0.1543 W/mK. However, the sample that possessed a 0.60% weight fraction of SF displayed higher thermal conductivity versus the sample with a 0.45% weight fraction of SF. This could be because the sisal fiber could be getting distributed non-uniformly in LFC after achieving optimum volume fraction (0.45%). The reduction in thermal conductivity with the rise in the SF volume fraction (up to optimum weight fraction) can be attributed to the natural fiber’s porous nature as well as the presence of lumen. Very low thermal conductivity pertaining to LFC composites could be due to the redistribution as well as the creation of smaller uniform pore void facilitated by the introduction of the SF [23]. This phenomenon yielded more multiple isolated pore voids when compared with the control with no addition of fiber. The results also showed the great potential of the sisal fiber to be employed in cement-based materials, such as LFC, where it can aid in decreasing the thermal inducing characteristics or heat transfer of concrete that is produced. Moreover, the produced LFC based on sisal fiber was found to include an

Table 2. Chemical composition of sisal fiber

Composition	%, dry weight
Lignin (%)	12.1
Cellulose (%)	56.4
Hemicellulose (%)	15.1
Moisture (%)	10.1
Wax (%)	1.7
Pectin (%)	4.6

Table 3. Mechanical properties of sisal fiber

Component	Properties
Tensile strength (MPa)	297
Young modulus (MPa)	17500
Fracture strain (%)	2.88

Table 4. Physical properties of sisal fiber

Component	Properties
Length of fiber	16–20 mm
Diameter of fiber	341–376 um
Width of lumen	13.76 um
Fiber density	1.26–1.44 g/cm ³



Fig. 1. Setup of thermal properties test

energy-saving perspective when employed as a green building material [23]. Indeed, in Malaysia, one of the green building requirements is to maintain low energy consumption; thus, if this composite material is employed for non-load-bearing structures or concrete precast walls, it could help to better insulate heat transfer from side to side versus ordinary LFC as well as could help to decrease energy consumption due to room temperature tuning [24].

Thermal diffusivity

The thermal diffusivity results of LFC reinforced with various weight fractions of sisal fiber are shown in Figure 3. As specified in Figure 8, the thermal diffusivity rises with an increase in the weight fraction of sisal fiber. This also

applies to the LFC’s thermal conductivity. As sisal fiber weight fraction of LFC increases from 0.15% BF to, 0.30% to 0.45%, the thermal diffusivity increases from 0.3523, 0.3635 to 0.3788 m²/sec, respectively. Introducing sisal fiber into LFC helps to improve the thermal diffusivity because of the low thermal conductivity associated with the sisal fiber and cellulose, lignin, and hemicellulose. The fiber’s fibrous nature, as well as the presence of lumen, also contributed to the porous fiber nature. With the high cellulose content associated with sisal fiber at 46.8% (see Table 2), the sisal fiber will absorb water promptly and possess excellent wettability to improve the LFC performance of the composite. The LFC material’s thermal diffusivity is the ability of composite material to facilitate the conduction of heat relative to the stored heat per unit volume.

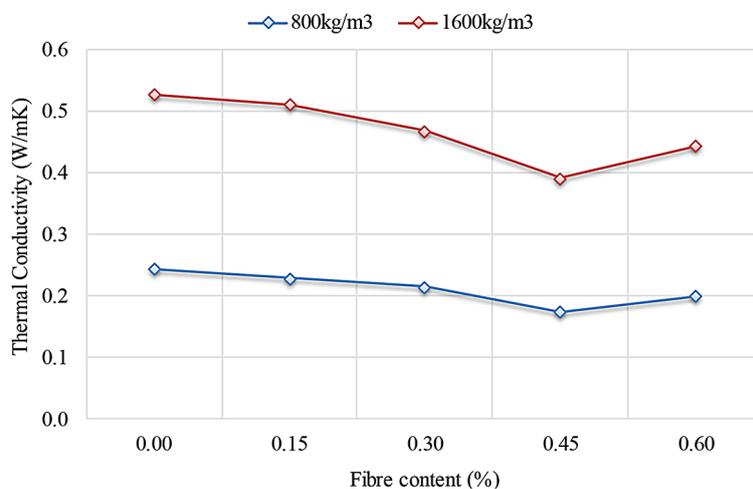


Fig. 2. LFC thermal conductivity with different weight fractions of sisal fiber

In other words, the LFC’s thermal diffusivity can be defined as the measure about how fast heat flows in the composite material. Consequently, if there is a rapid flow of heat within a composite’s material, the material is regarded to be a good thermal conductor [25]. In contrast, if there is a slow heat flow within a composite’s material, then it is regarded to be a good thermal insulator. In this case, introducing the sisal fiber into LFC improves the rate of heat flow, thus conferring it an excellent thermal insulator property [26].

Specific heat capacity

Specific heat capacity can be defined as a measurement employed for determining heat energy released or absorbed by a substance as a unit when temperature decreases and increases by 1K. More energy is required to raise its temperature

when there is an increase in the specific heat energy of a material. Moreover, a material’s ability to retain heat as well as conserve energy in buildings can also be referred to as high specific heat. Specific heat capacity is important for heat retention, thereby contributing to the material’s thermal mass. The specific heat capacity results pertaining to LFC reinforced with various weight fractions of sisal fiber are shown in Figure 4. This study had confirmed that the inclusion of sisal fiber in all weight fractions led to reduced specific heat capacity compared to the control specimen which had a specific heat capacity of 0.5231 W/mK. The best result pertaining to specific heat capacity was achieved when a 0.45% volume fraction of sisal fiber was added. The specific heat capacity was found to be 0.4028 W/mK. The sample that had a 0.60% weight fraction of sisal fiber displayed higher specific heat capacity versus a 0.45%

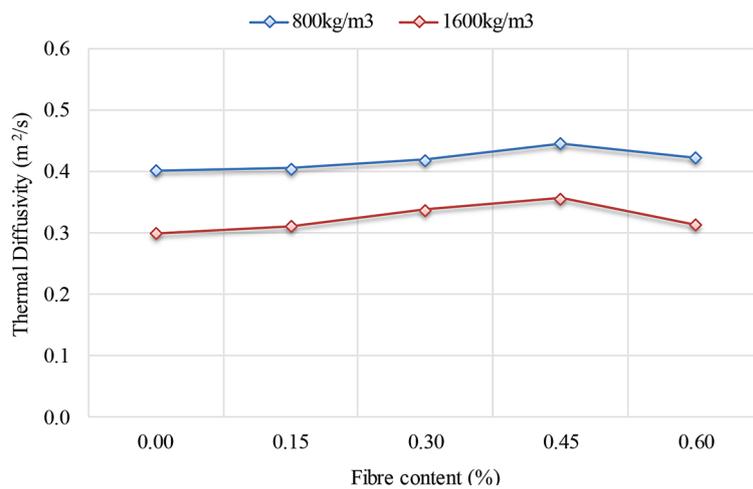


Fig. 3. LFC thermal diffusivity with different weight fractions of sisal fiber

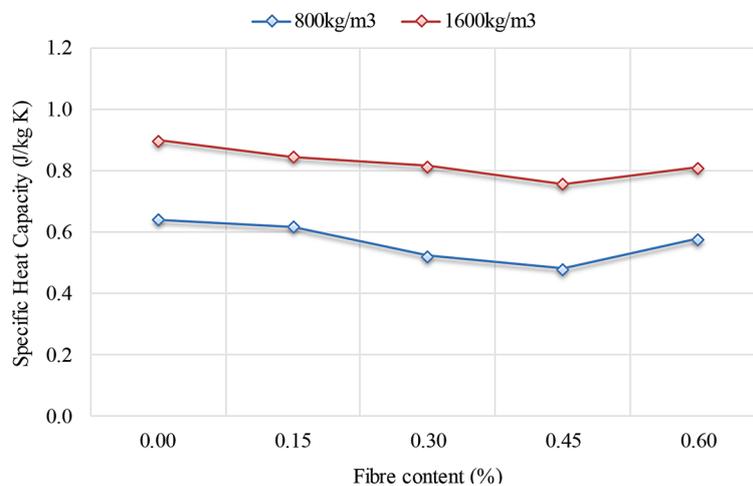


Fig. 4. LFC specific heat capacity with different weight fractions of sisal fiber

weight fraction of SF. Thus, it is clear that the addition of SF in LFC results in a decrease in the specific heat of sisal fiber paste (up to optimum weight fraction at 0.45%) because of the interface between sisal fiber and cement, which contributes to the specific heat components associated with the element of vibrations [27].

Thermal conductivity and thermal diffusivity relationship

A key role is played by diffusivity and thermal conductivity with regards to transferring the characteristics of cement-based materials, such as LFC. These two parameters are regarded to be crucial for understanding the role of a fracture network in the prediction of the thermal conductivity of porous media. Consequently, this evaluation makes an effort to observe the interactions that occur between thermal diffusivity and thermal conductivity pertaining to LFC reinforced with sisal fiber. Figure 5 displays the correlation that exists between thermal diffusivity and thermal conductivity with regards to the addition of SF in LFC. The direction of the line implies that as thermal conductivity declines due to an increase in SF weight fraction, thermal diffusivity increases [28]. Similarly, an increase in thermal conductivity will equally result in a corresponding decrease in thermal diffusivity. The regression analysis offers the best inclinations with regards to designating the relationship that exists between thermal diffusivity and thermal conductivity, which can also be provided as a linear function. An R^2 value of 0.9665 suggests the existence of a strong

correlation between thermal diffusivity and thermal conductivity with regard to foamed concrete.

Thermal conductivity and specific heat capacity relationship

Figure 6 shows the relationship that exists between specific heat capacity and thermal conductivity pertaining to LFC when sisal fiber is introduced. The regression analysis offers the best tendencies with regards to specifying the relationship that exists between specific heat capacity and thermal conductivity, which can also be represented as a linear function. An indirect variation is demonstrated by the straight-line graph, which is between the specific heat and the thermal conductivity. In such a case, the specific heat capacity increases with a decrease in the thermal conductivity because of the addition of sisal fiber weight fraction. An R^2 value of 0.9532 demonstrates the existence of a very strong correlation between the specific heat capacity and the thermal conductivity.

Thermal diffusivity and specific heat capacity relationship

Figure 7 shows the correlation that exists between specific heat capacity and thermal diffusivity pertaining to LFC when sisal fiber is introduced. The direction of the straight-line graph depicts that as thermal diffusivity increases due to fiber volume fraction, specific heat capacity declines. This consistently means that the addition of sisal fiber in LFC results in a reduction in the values of specific

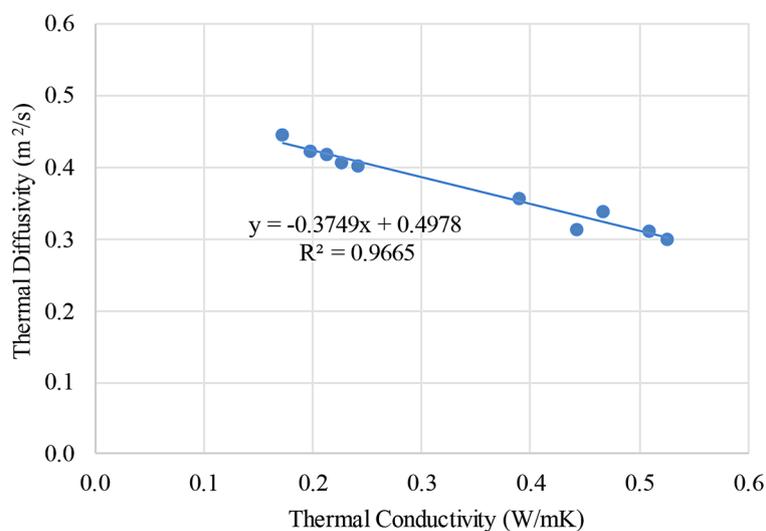


Fig. 5. LFC thermal conductivity and thermal diffusivity relationship

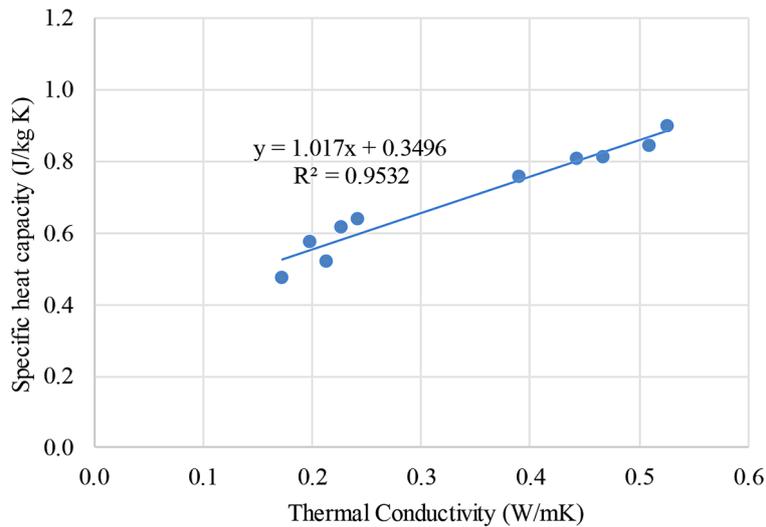


Fig. 6. LFC thermal conductivity and specific heat capacity relationship

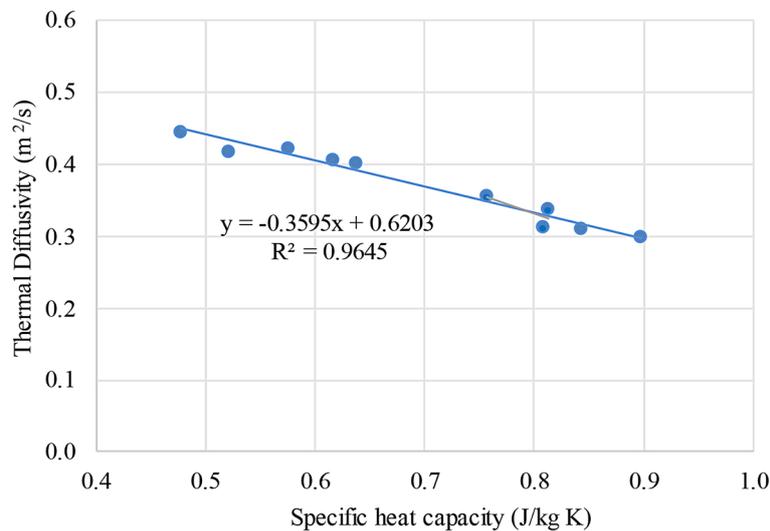


Fig. 7. LFC thermal conductivity and specific heat capacity relationship

heat capacity of the composites material. The regression equation for this relationship is shown in Figure 7. With regards to the regression equation, the R^2 value is 0.9645, suggesting the existence of a strong correlation between the specific heat capacity and the thermal diffusivity of LFC.

CONCLUSION

This research study concentrates on identifying the thermal characteristics of LFC when various weight fractions of sisal fiber are introduced into LFC. For testing, we prepared densities of 800 kg/m³ and 1600 kg/m³, with five

different weight fractions with the introduction of sisal fiber, i.e., 0.00%, 0.15%, 0.30%, 0.45% and 0.60%. As per the experimental results, the optimum inclusion of a 0.45% weight fraction of sisal fiber offered the best results, with regard to the thermal characteristics (thermal conductivity, specific heat capacity, and thermal diffusivity). At a weight fraction of 0.45% sisal fiber, maximum compaction was achieved by the fibers as well as the cementitious matrix, which can be attributed to the optimum mix uniformity. Moreover, this also resulted in the optimum level of sisal fiber addition, non-uniform dispersion of fibers, and optimum accumulation, which resulted in dropping in the entire thermal characteristics evaluated.

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