MARMARA UNIVERSITY
FACULTY OF ENGINEERING

EXPERIMENTAL ANALYSIS OF POLYURETHANE MATRIX PARTICULATE AND FLAKE COMPOSITES INORDER TO INCREASE ACOUSTIC ABSORPTION PROPERTY

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ABSTRACT

Experimental Analysis of Polyurethane Matrix Particulate and Flake Composites In order to Increase Acoustic Absorption Property

The sound absorption property of polyurethane foams loaded with expanded particulate perlite and nutshell also expanded flake perlite has been studied. The acoustical parameter selected for this study is ‘‘sound absorption coefficient’’. The results show there are significant improvements in the sound absorption property in some frequencies and there are some regressions in some frequencies. Using flake perlite as a filler material improves sound absorption properties of soft foam at 0 to 1000 Hz. Using particulate perlite higher than %50 weight ratio improves sound absorption properties of foam at 0 to 5000 Hz. Particulate nutshell improves sound absorption properties higher than %60 weight ratio. It is pleasing to see that adding expanded perlite and particulate nutshell to the polyurethane foam demonstrate a significant contribution to sound absorption properties of the material and it encourages using environmental friendly products as sound absorption material in further studies.

ABBREVIATIONS

ASTM **:** American Society for Testing and Materials

FAOSTAT **:** United Nations Food and Agriculture Organization, Statistics Division

ISO **:** International Organization for Standardization

MOCA **:** Methylene-bis-ortho-chloroanilline

NS **:** Particulate Nutshell

PET **:** Polyethylene Terephthalate

PLT **:** Particulate Expanded Perlite

PU **:** Polyurethane

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1. INTRODUCTION

Polymer-based foams are widely used in industry to benefit from their mechanical, electrical, thermal and acoustic properties (VERDEJO et al., 2009). Polyurethane (PU) is one of the polymers with the largest and most versatile applications having the ability to easily change its properties by changing the chemical composition or adding filler reinforcement agents. It is commonly used as adhesives to join different materials in the footwear and automotive industry.

There are many studies of PU composites involving the use of additive material such as glass, carbon, boron, nylon, and kevlar. The tensile properties of polyurethane foams can be increased using polyester, glass, Kevlar-49 aramid fiber (CHEN, MA, 1992a; 1992b; 1994; VAIKHANSKI, NUTT, 2003a; 2003b), carbon nanotubes (VERDEJO, 2009), multi-walled carbon nanotubes (CHEN, 2006), methylenebis-ortho-chloroanilline (MOCA)-grafted carbon nanotubes (XIONG, 2008), SiO2 (YANG, 2004), silexil (SALIBA et al., 2005), post-consumer PET (polyethylene terephthalate) (MELLO, 2009), and mineral fillers such as calcium carbonate and crystallized silica particles (SAINT-MICHEL et al., 2006). Pure carbon nanotubes (KUCEROVA et al., 2009), multiwalled carbon nanotubes (CHEN, 2006), and silexil (SALIBA, 2005) contribute to the Young's modulus of PU foam composites.

Among the coconut and woven sisal fabric mixed PU composites, alkali-treated coconut fibers exhibit the best fracture toughness (SILVA, 2006). Among the pine wood and hemp fibers used to reinforce microcellular cross-linked PU synthesized from a castor oil-based polyol, hemp fibers provide the best dynamic flexibility, modulus and toughness characteristics (ARANGUREN, 2007). Abrasive properties of PU foam can be increased by adding garnet particles into the mixture (JANG, 2001). Stacking hardwood-based cellulose fiber mats between polyurethane films and using compression molding improves the tensile strength and modulus properties (SEYIDBEYOĞLU, 2008). Among the cotton, bamboo and wool fibers mixed with polyurethane foam, cotton fibers result in the best sound absorption properties (BÜYÜKAKINCI, 2011).

Recently, granular materials have been studied for different acoustic treatment due to their sound absorptive and sound insulating properties. Properties of granular materials are of great importance in many areas of acoustics and noise control. These products, combined with cementitious, polyurethane or epoxy binders, show a good degree of structural strength and durability with high values of acoustic absorption (BENKREIRA, KHAN, HOROSHENKOV, 2011).

Sound absorption constitutes one of the major requirements for human comfort today, especially in automobiles and manufacturing environments. These applications create a higher sound pressure and thereby the need to develop more efficient and economical ways of producing sound absorption materials. Industrial applications of sound absorption generally include the use of materials such as glass wool, foam, mineral fibers and their composites. Using a laminated polyester fabric composed of different layers bonded by polyurethane adhesive doped with a removable salt are already studied to determine the sound permissibility levels in automobiles (MAHMOUD et al., 2011)

This study investigates the effect of flake expanded perlite also particulate expanded perlite and particulate nutshell as agents on sound absorption properties of polyurethane foam. The reason of selecting expanded perlite as a material in the production of sound absorbing composites is that expanded perlite, a kind of porous material, is also used as sound absorption and thermal insulation material. The reason of selecting nutshell is that to have another component to make comparison about materials' sound absorption effect to polyurethane foam.

Perlite is an amorphous volcanic glass that has a relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its low density after processing. Perlite softens when it reaches temperatures of 850–900 °C (1,560–1,650 °F). Water trapped in the structure of the material vaporizes and escapes, and this causes the expansion of the material to 7–16 times its original volume. The expanded material is a brilliant white, due to the reflectivity of the trapped bubbles. Unexpanded "raw" perlite has a bulk density around 1100 kg/m^3 (1.1 g/cm^3), while typical expanded perlite has a bulk density of about 30–150 kg/m^3 (0.03-0.150 g/cm^3). (MAXIM et al., 2014). Perlite is a non-renewable resource. The world reserves of perlite are estimated at 700 million tonnes. Perlite is a non-renewable resource. The world reserves of perlite are estimated at 700 million tonnes. In 2011, 1.7 million tonnes were produced, mostly by Greece (500,000 tonnes), United States (375,000 tonnes) and Turkey (220,000 tonnes). However, no information for China – a leading producer – was available. (BOLEN, 2013). Therefore, perlite is easy to find material. Nutshell is the outer shell of a hazelnut. It is actually a waste of hazelnut. In 2016, world production of hazelnuts (in shells) was 743,455 tonnes, a 20% decrease from 2015.Turkey produced 57% of the world total (420,000 tonnes), followed by Italy (120,600 tonnes), the United States (34,500 tonnes), Azerbaijan (33900 tonnes) and Georgia (29,500 tonnes). (FAOSTAT, 2017).

In this study, different compositions of expanded perlite and nutshell particles with PU are used in the development of a new sound absorbent material.

2. EXPERIMENTAL SETUP

Rigid PU foam (Lupranat M20s isocyanate mixed with Puranol RF 4110 polyol) are used as matrix materials. The composition of polymers has given in Table2.1.

Table 2.1. Properties of Puranol RF4110 Polyol and Lupranat M20s isocyanate.

Physical properties	Unit	Polyol	Isocyanate
density (25^oC)	g/cm^3	-	1.24
viscosity (25^oC)	mPa.s	4000	210
NCO content	%	-	31.5
Storage life	Month	6	6

2.2. Preparation of Expanded Perlite Particles Mixed PU Samples

Composite samples are prepared by mixing expanded perlite particles with a polyurethane formulation including isocyanate, polyol, surfactant and water. Surfactant and water were used for speed up the reaction and faster foam formation.

At the beginning of the study it was necessary to define different weight ratios of PLT in PU. For this purpose, the maximum weight ratio must be defined. In order to determine the maximum amount of PLT that can be added to PU, many samples having different PLT weight ratios are produced. Then, the maximum weight ratio is obtained. The range of weight ratio of PLT varies between zero and the maximum weight ratio. Weight ratios are determined in this range and samples are prepared.

The composition ratio of PU is constant. We determined the weight ratios of components with Equivalent Weight of a Polyol (2.1), and Equivalent Weight of a Isocyanate (2.3) formulas.

$$Equivalent\ Weight\ of\ a\ Polyol = \frac{56.1 \times 1000}{OH\ Number} \tag{2.1}$$

where 56.1 is the atomic weight of potassium hydroxide and 1000 is the number of milligrams in one gram of sample.

OH Number: A number arising from a wet analytical method for the hydroxyl content of a polyol; it is the milligrams of potassium hydroxide equivalent to the hydroxyl content in one gram of polyol or other hydroxyl compound. It is provided 450 mg KOH/g for Puranol RF 4110 by the manufacturer.

$$Equivalent\ Weight\ of\ a\ Polyol = \frac{56100}{450} = 124.66\,\frac{g}{eq} \tag{2.2}$$

$$Equivalent\ Weight\ of\ a\ Isocyanate = \frac{4202}{\%NCO} = \frac{4202}{31.5} = 133.39\,\frac{g}{eq} \tag{2.3}$$

We prepared samples of 25% of these results. So we determined the weight of polyol is 31.15 g and the weight of isocyanate is 33.32 g in each sample. Then we used surfactant and water for speed up the reaction and faster foam formation. Total weight of foam composition without additive became 69.17 g. We determined the weight of additive materials based on total weight of foam composition. Table 2.2. and 2.3. show the weight ratios of the first samples.

Table 2.2. Puranol RF 4110 polyol and isocyanate with PLT (0-1mm particle size).

Sample	PLT		Polyol		Isocyanate		Surfactant		Water	
	%w	g	%w	g	%w	g	%w	g	%w	g
PUPLT10	9.1	6.91	40.9	31.15	43.8	33.32	5	3.77	1.2	0.93
PUPLT40	28.5	27.64	32.2	31.15	34.4	33.32	3.9	3.77	1	0.93
PUPLT50	33.3	34.55	30	31.15	32.2	33.32	3.6	3.77	0.9	0.93
PUPLT60	37.5	41.46	28.2	31.15	30.1	33.32	3.4	3.77	0.8	0.93
PUPLT70	41.2	48.37	26.5	31.15	28.3	33.32	3.2	3.77	0.8	0.93
PUPLT80	44.4	55.28	25	31.15	26.8	33.32	3	3.77	0.8	0.93
PU	0	0	45	31.15	48.2	33.32	5.5	3.77	1.3	0.93

Table 2.3. Puranol RF 4110 polyol and isocyanate with PLT (0.5-3mm particle size).

Sample	PLT		Polyol		Isocyanate		Surfactant		Water	
	%w	g	%w	g	%w	g	%w	g	%w	g
PUPLT6	5.6	4.14	42.5	31.15	45.5	33.32	5.1	3.77	1.3	0.93
PUPLT10	9.1	6.91	40.9	31.15	43.8	33.32	5	3.77	1.2	0.93
PUPLT15	13	10.36	39.2	31.15	41.9	33.32	4.8	3.77	1.1	0.93
PUPLT20	16.6	13.82	37.5	31.15	40.1	33.32	4.5	3.77	1.1	0.93
PU	0	0	45	31.15	48.2	33.32	5.5	3.77	1.3	0.93

Polyol and surfactant are mixed with PLT at determined weights. Then isocyanate and water added and mixed in order to obtain a homogeneous compound. From each mold, sample with diameter of 100 mm for large tube measurements (Figure 2.1a) and a smaller round piece with a 29 mm diameter for small tube measurements (Figure 2.1b) were obtained.

Figure 2.1a. Perlite included sample for the large tube (100mm diameter)

Figure 2.1b. Perlite included sample for the small tube (29mm diameter)

2.3. Preparation of Hazelnut Shell Particles Mixed PU Samples

Hazelnut shell particles were used as additive in PU. Table 2.4. shows the weight ratios of samples.

Table 2.4. Puranol RF 4110 polyol and isocyanate with NS (0-1mm particle size).

Sample	NS		Polyol		Isocyanate		Surfactant		Water	
	%w	g	%w	g	%w	g	%w	g	%w	g
PUNS10	9.1	6.91	40.9	31.15	43.8	33.32	5	3.77	1.2	0.93
PUNS40	28.5	27.64	32.2	31.15	34.4	33.32	3.9	3.77	1	0.93
PUNS60	37.5	41.46	28.2	31.15	30.1	33.32	3.4	3.77	0.8	0.93
PUNS70	41.2	48.37	26.5	31.15	28.3	33.32	3.2	3.77	0.8	0.93
PU	0	0	45	31.15	48.2	33.32	5.5	3.77	1.3	0.93

PU foams with hazelnut shell particles as additive were prepared in the same way as expanded perlite. Sample with diameter of 100 mm for large tube measurements (Fig. 2.2a) and 29 mm diameter for small tube measurements (Fig. 2.2b) were obtained.

Figure 2.2a Hazelnut shell included sample for the large tube (100mm diameter).

Figure 2.2b Hazelnut shell included sample for the small tube (29mm diameter).

2.4. Measurements of Acoustic Properties

The testing apparatus is part of a complete acoustic material testing system featuring a Brüel& Kjær PULSE™ interface (Fig. 2.3.). In this study only an impedance tube kit 4206 was used.

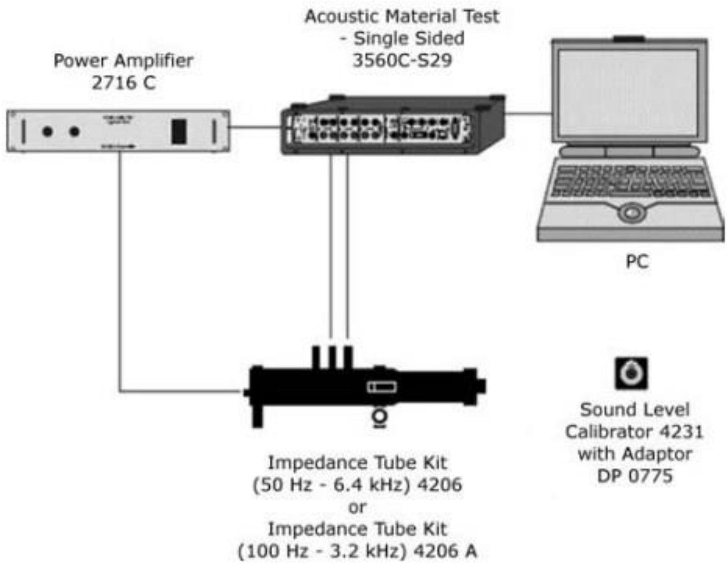

Figure 2.3 Measurement tester of acoustic properties (courtesy of Brüel & Kjaer).

The sound absorption measurements were performed according to ISO 10534-2 and ASTM E1050- 98 international standards for horizontally mounted orientation-sensitive materials using a two-microphone transfer-function method. The small impedance tube kits consisted of a 29 mm diameter tube, a sample holder, and an extension tube of the same diameter. The large impedance tube kit consisted of a similar tubular apparatus with a diameter of 100 mm. The small and large tube setups were used to measure different acoustical parameters and then large and small tube measurements were combined to determine the sound absorption coefficient for the frequency range of 0–6.4kHz Hz.

3. RESULTS AND DISCUSSION

PU foam, expanded perlite and nutshell particle composites are produced and sound absorption coefficients are measured for three times. The average values are plotted as graphs to make comparison. The sound absorption coefficient values obtained are plotted for the composite of Puranol RF 4110 Polyol Foam(PU) and the PLT. The samples have 2 cm thickness. The absorption coefficient values are also plotted for the NS.

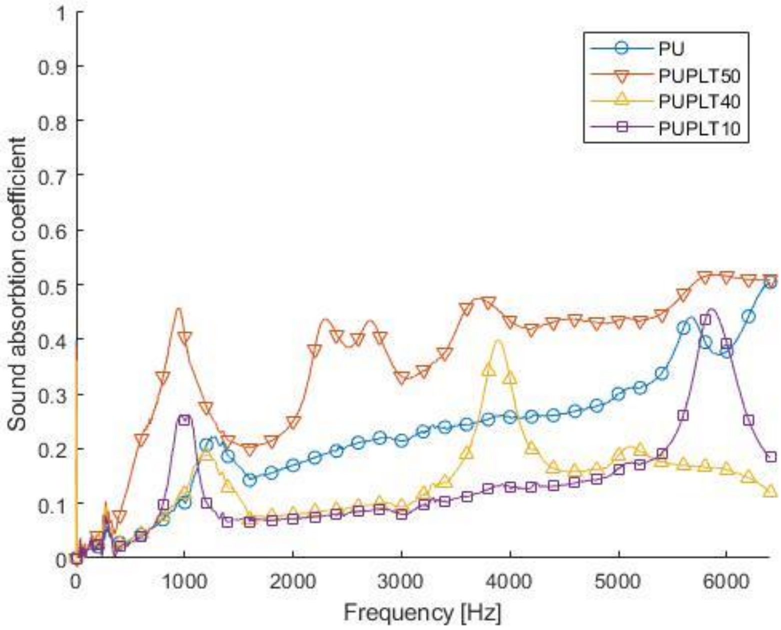

Figure 3.1. Sound absorption of PU foam and PLT (0-1mm particle size) composites.

The sound absorption of pure PU is similar to PUPLT10,PUPLT40 between 0-1.2 kHz frequencies. (except 3.7kHz to 4.1kHz for PUPLT40). But the sound absorption of PU is above between 1.2kHz-6.4kHz frequencies when compare with PUPLT10 and PUPLT40.

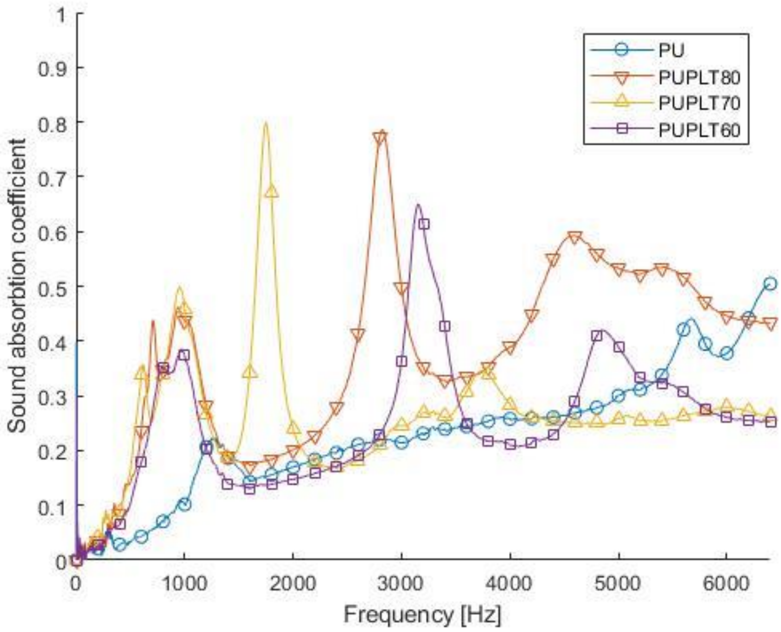

Figure 3.2. Sound absorption of PU foam and PLT (0-1mm particle size) composites.

The sound absorption of all samples on this figure is higher than pure PU between 0-1.4kHz frequencies. The sound absorption of PUPLT70 significantly improved between

1.4-2 kHz. The sound absorption of PUPLT80 is significantly increased between 2.5-6.4 kHz and the maximum value 0.75 on near 2.9 kHz. For PUPLT60, the sound absorption increased significantly between 3-3.8 kHz frequency range.

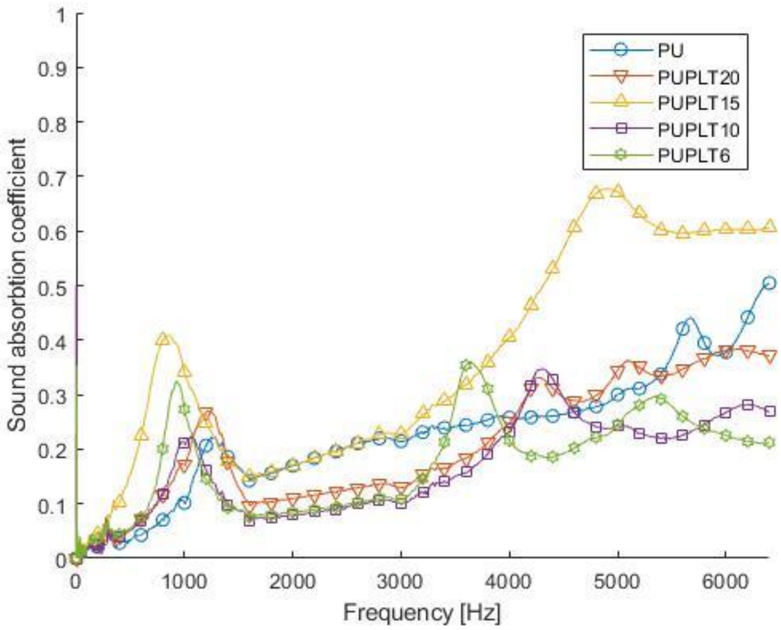

Figure 3.3. Sound absorption of PU foam and PLT (0.5-3mm particle size) composites.

All the samples have higher sound absorption than pure PU between 0-1.3kHz frequencies. The sound absorption of PUPLT20, PUPLT10 and PUPLT6 is lower than pure PU between 1.5kHz-6.4kHz.(except between 3.4kHz-3.9kHz for PUPLT6, between 4.1kHz-4.7kHz for PUPLT10, between 4.1-5.4kHz for PUPLT20). Sound absorption of PUPLT15 is higher than pure PU at all frequency ranges.

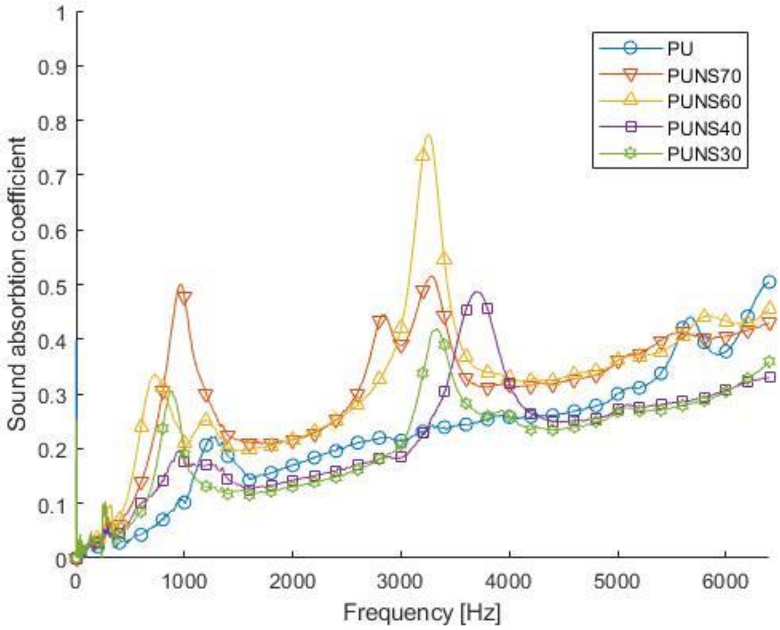

Figure 3.4. Sound absorption of PU foam and NS (0-1mm particle size) composites.

The sound absorption of all NS samples is higher than pure PU between 0-1.2kHz frequency range. Sound absorption of PUNS30 and PUNS40 is lower than pure PU between 1.2kHz-6.4kHz.(except between 3kHz-3.7kHz for PUNS30, and 3.3kHz-4.2kHz for PUNS40). Sound absorption of PUNS60 and PUNS70 is higher than pure PU at all frequency ranges.

4. CONCLUSIONS

The increased agricultural production and the development of agro-based industries in many countries of the world have brought about the production of large quantities of agricultural wastes, most of which are not adequately managed and utilized. Agricultural wastes were used for animal feed, fertilizer and fuel for energy production, but little work has been carried out to develop utilization of these wastes in the production of industrial materials. This study tried to fill this gap and showed an area to reuse wasted NS.

NS is a wasted by product of hazelnut. Also, the NS is hygienic, a product of renewable bioresources, and is biodegradable. Using a novel natural improves the sound absorption properties and causes lessening the environmental impact and reducing the cost of the developed material.

Perlite, an industrial mineral and amorphous volcanic glass also has been used as additive material because its already used in industrial sound absorption and this study tried to find new additive materials which can be added to PU in order to increase sound absorption property.

The NS and PLT mixed polyurethane-based composites are developed and acoustic measurements are performed to determine their sound absorption properties.

Including PLT and NS into PU improves the sound absorption properties significantly. Only 2 sample's absorption values decreased. The sound absorption property has improved 50% and higher PLT containing samples. The results show that there are peak points on some exact frequency ranges. Sound absorption coefficient increases almost %400 on that points.

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