Review

Insight into Materials Engineering of *Eucommia ulmoides* Gum

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The materials engineering of *Eucommia ulmoides* gum (EU gum) and the development of its new products are briefly described. This is followed by introduction of the development of low molecular weight EU gum and EU resin, the damping properties of rubbers blended with EU gum, and the dynamic mechanical properties of PBA/PS binary- and EU gum/PBA/PS-ternary-interpenetrating polymer networks. Finally, their prospective applications are discussed.

Key words: *Eucommia ulmoides* gum; materials engineering; damping properties; dynamic mechanical properties and order flexible chains

Fig. 1. Linear crystalline microscopic structure of EU gum at stage A

Fig. 2. Partial crystalline network microscopic structure of EU gum at stage B

Brief Introduction of Materials Engineering of *Eucommia ulmoides* Gum¹⁾

1. Three Characteristics of Molecular Chain of EU Gum:

The chemical structure of EU gum¹⁾ is as shown below.

Two methylenes are present on both sides of the double bond; therefore, the chemical name of this structure is *trans*-polyisoprene. This molecular chain has three characteristics: order property, double bonds, and flexibility.

It can be easily crystallized owing to the order property of the *trans* structure.

The double bonds can be vulcanized to form a crosslinked network structure.

Its flexible chain imparts chain elasticity.

If its double bonds are vulcanized to form the crosslink structure and the crosslink degree is high enough to effectively depress the crystal, EU gum can be processed into a high elastomer. The control of the crosslink degree reveals three stages of the vulcanization process of EU gum.

2. Three Stages of Vulcanization Process of EU Gum:

Table 1 shows that at stage A, the microscopic structure of EU gum is a linear crystal polymer (Fig. 1); at room temperature, it is a rigid solid and above its melt point, it is a thermoplastic. Further, on the application of an external force, its deformation is irreversible.

At stage B, its microscopic structure is a partial crystal network (Fig. 2); at room temperature, it is a rigid solid and above its melt point, it transforms into a high elastomer. EU gum at this stage is called a thermoelastomer.

At stage C, the crosslink degree has attained the critical value; the crystals in the network disappear (Fig. 3). EU gum has transformed into a high elastomer.

On comparing Figs. 3 and 4, we can see the difference between the microscopic amorphous network structure made of ordered chains of EU gum at stage C and the random coil network structure of NR.

3. Materials Engineering of EU Gum:

The discovery of the three stages of the vulcanization process of EU gum implies that the research and development of EU gum has entered a new stage of systematic materials engineering.

The right side of Table 2 shows EU gum as the main component that can be processed into three different types of

Table 1. Three stages of vulcanization process of EU gum

Stage	Degree of crosslink	Microscopic structure	Macroscopic property
A	Zero-degree of crosslink	Linear crystalline polymer	Thermoplastic
B	Low degree of crosslink	Partial crystalline network	Thermoelastomer
C	Critical degree of crosslink	Amorphous network	High elastomer

Fig. 3. Microscopic amorphous network structure of EU gum at stage C **Fig. 4.** Random coil network structure of NR**Table 2.** Materials engineering of EU gum

EU gum (<i>trans</i> -polyisoprene)						
Blend				Single component		
With plastic		With rubber		Control vulcanization		
Unvulcanization	Vulcanization	Control vulcanization	Stage C	Stage B	Stage A	
Improved plastics	Thermoplastic elastomer	Thermoelastomer	High elastomer	High elastomer	Thermoelastomer	Thermoplastic

Fig.5. Chest protector made of EU gum **Fig.6.** Shape memory connecting tube made of EU gum for vacuum water pump

materials by controlling the crosslink degree: thermoplastics, thermoelastomer, and high elastomer.

The left side of Table 2 shows that by blending EU gum with rubbers and plastics, a series of different materials high elastomer, thermoelastomer, thermoplastic elastomer, and improved plastics are obtained. Therefore, the uses of EU gum cover a very broad range from plastics to high elastomer. This implies that no material is used over as wide a range as EU gum.

4. A Series of Patented Products of EU Gum:

A series of patented products have been developed through materials engineering of EU gum.

A medical orthopedic product for externally fixing splints a replacement for plaster with excellent forming properties because of its low melting point at stage A (Fig.5).

A shape memory connecting tube developed by using the thermoelasticity of EU gum at stage B (Fig.6).

Motorcycle tires (3.25-16 type) made of EU gum/BR (1/1) blend have a performance lifetime of two years (Fig.7).

A high sealing film that is air tight and has excellent transparency to radar wave has been developed by improving EU gum (Fig.8).

Further Research & Development of EU Gum

1. Development of Low Molecular Weight EU Gum and EU Resin²⁾

Low molecular weight EU gum and EU resin are melting states with high viscosity and adhesion above the melting point. They can be used as adhesives or improving agents. Table 3 shows the mechanical properties of BR* improved by EU gum.

The above result shows that the mechanical properties of BR improved by EU resin have evidently increased. Particularly, its dynamic tensile fatigue is much higher than that

Fig. 7. 3.25-16 type motorcycle tires made of EU gum/BR (1/1) blend

Fig.8. Sealing film made of EU gum for radar antenna

Table 3. Mechanical properties of BR* improved by EU resin.

	Tensile strength (MPa)	Tear strength (MPa)	Akron abrasion	Dynamic tensile fatigue** (times)
BR	20	4.9	0.075	33000
BR improved by EU resin	22	6.1	0.09	>100000

*BR: butadiene rubber; **tensile ratio: 200%

Table 4. Hysteresis loss ratios of several pure rubbers

Rubber	NBR*	IIR*	EPDM*	CR*	NR	SBR*	BR
Hysteresis loss ratio	24.2	17.8	16.3	11.8	5.9	5.6	4.5

*NBR, acrylonitrile-butadiene rubber; IIR, isobutene-isoprene rubber; EPDM, ethylene-propylene-diene rubber; CR, chloroprene rubber; NR, natural rubber; SBR, styrene-butadiene rubber.

Table 5. Hysteresis loss ratios of several rubbers blended with EU gum

	NBR/EU gum	IIR/EU gum	EPDM/EU gum	CR/EU gum	NR/EU gum	SB/EU gum	BR/EU gum
Hysteresis loss ratio	31.6	23.9	21.4	22.5	14.8	3.7	17.2

Fig. 9. $\tan\delta$ -T curve of dynamic mechanical behavior of PBA/PS binary-interpenetrating polymer network and $\tan\delta$ -T curve of dynamic mechanical behavior of EU gum/PBA/PS ternary-interpenetrating polymer network.

of unimproved BR. Normally, the mechanical properties of unimproved BR are quite poorer than those of other rubbers. The improving of mechanical properties of BR mixed with EU resin can be dependant on the improving in the stress-distribution in microscopic network to decrease stress concentration. This feature has an important application value.

2. Damping Properties of Rubbers Blended with EU Gum³⁾

A comparison between Table 4 and Table 5 shows that all the hysteresis loss ratios of the rubbers blended with EU gum are visibly higher than those of pure rubbers. This feature will lead to the development of a new application of EU gum.

3. Dynamic Mechanical Properties of PBA/PS binary- and EU gum/PBA/PS-ternary-interpenetrating Polymer Networks⁴⁾

Curve 1 in Fig. 9 is $\tan\delta$ -T curve of dynamic mechanical behavior of PBA/PS binary-interpenetrating polymer network and curve 2 is that of EU gum/PBA/PS ternary-interpenetrating polymer networks.

The two curves show that the damping property of the EU gum/PBA/PS ternary-interpenetrating polymer network is much better than that of the PBA/PS binary system because the $\tan\delta$ value of curve 2 is higher than that of curve 1 between -20°C ~ $+80^{\circ}\text{C}$.

Discussion

Above results means that the flexible molecular ordered chain of EU gum has excellent potential to improve the mechanical properties of rubbers and specially the damping properties of rubbers, no matter for blends ,copolymers or interpenetrating polymers.

This implies that the future of further research and development on EU gum and EU resin is very bright.

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