PREPARATION AND PERFORMANCE ANALYSIS OF A NATURE-INSPIRED ANTI-CUT MATERIAL

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Keywords: *Nature-inspired, anti-cut, Na-magadiite, lattice structure*

1 Abstract

Anti-cut material have experienced a rapid growth, however, an still existing limit is a perfect combination of strength and flexibility. As a natural mineral, Na-magadiite ($Na_2Si_{14}O_{29}\ nH_2O$) are used to prepare molecular sieve for its particular physical and chemical properties. Inspired by this, simulating the structure of Na-magadiite, we designed a novel anti-cut material, in order to overcome the deficiencies of current ones. Stiff particles reinforced special resin matrices lattice structure (Fig.1) was used for both resistance to blade and elimination of consecutive linear gap that allows blade to pass through to make the material more flexible. By changing the parameters in process, we obtained the optimal structure in anti-cut performance, flexible performance and overall performance. Moreover, the effects of several major factors on anti-cut and flexible performance were discussed.

2 Introduction

In modern society, protective clothing material experiences increasing development[1]. *DuPont Co*. has developed an anti-cut glove with Kevlar fiber, and it has a resistance to cut and abrasion even in high temperature[2]. One great anti-cut material should be a perfect combination of strength and flexibility. It has been well known that structure from nature have remarkable properties[3]. Bio-inspired materials and devices are attracting increasing interests because of their unique properties, which have paved the way to many significant applications[4,5,6]. As a natural structure, Na-magadiite ($Na_2Si_{14}O_{29}\ nH_2O$) was first found at Magadi in Kenya by Eugster[7]. A structure model[8,9] accepted by most researchers is followed(Fig. 1). Because of its netted crystalloid[10] and particular chemical properties[11], it has been widely used to prepare molecular sieve. Some researcher have payed their attention on anti-cut material[12,13], however, self-locking effect, multi-layer and steel wire all can resulted in the reduction of flexibility, while high qualified fibers have a relatively high cost. In order to overcome these deficiencies, some stiff materials were used as the reinforcement to prepare a polymer lattice anti-cut material. It has many advantages such as high strength, high flexibility and low cost. In this research, a novel anti-cut material is designed by simulating the structure of Na-magadiite to overcome the deficiencies of current ones.

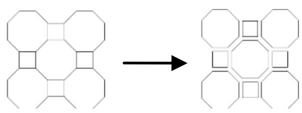
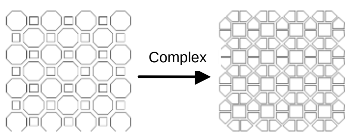
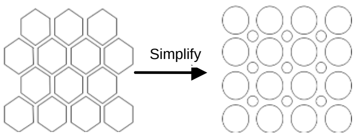


Fig.1. Schematic representation of Na-magadiite lamination structure

Based on this, the shape group was broaden to other crystal structure[11, 14], such as hexagon[15] (Fig 2c) from the structure of graphene. Through transforming, two new shape groups were found, quadrilateral/pentagon (Fig 2b) and big round/small round(Fig 2d).



a b



c d

Fig.2. Four kinds of graphic design of the anti-cut materials

3 Experimental

3.1 Matrix and Reinforcement

The epoxy was used as the matrix system, which includes epoxy and amine curing agent. The two components were mixed in proportion. Glass microballoon was added as reinforcement. The whole system was place on a terylene cloth.

3.2 Evaluation

The influence of shape group, size and thickness on the anti-cut performance was tested according to EN388-2003 standard[16] in order to get an optimized proposal orthogonal test. All samples were prepared with the same size. 16 samples are obtained by changing the parameter, and are tested according to the orthogonal table (Table 1).

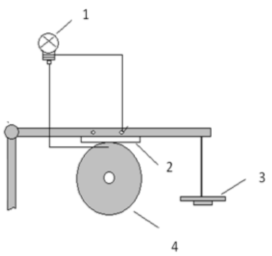
Table 1 Anti-cut material testing factors and level

Factor / Series	A Shape group	B Thickness/mm	C Size (proportion to standard)
1	Quadrilateral/octagon	0.26	0.5
2	Hexagon	0.39	1
3	Big round/small round	0.52	1.5
4	Quadrilateral/pentagon	0.65	2

The equipment in EN388-2003 standard[16] was improved (Fig3, Fig4). A sample sized 50*50mm was set on the 200mm-diameter wheel. The blade (Table 2) was loaded to 30N. When testing, the wheel was rotating there and back at a rotate speed of 100mm/s, with the blade in touch with the sample all the time. It can be concluded fail if the blade penetrates the sample. In order to evaluate the effect, resin coverage rate η was defined. A mathematic model was used to simulate the variation of η of different direction, therefore the position which has the η_{max} and η_{min} can be obtained. The position of η_{min} is at the linear gap. According to the analysis of η, the position of η_{max} and η_{min} were tested.

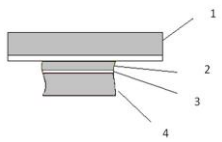
Table 2 The basic parameters of tools

Size（L×W×H）/mm	Sharpness	HRC
100×18×0.5	17.2°	53



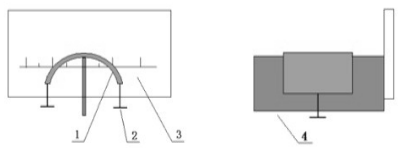
1-light 2-blade 3-weight 4-wheel

Fig.3. Anti-cutting performance test device



1-blade 2-sample 3-aluminum foil 4-wheel

Fig.4. The location relationship of the blade cut-off point



1-sample 2-weight 3-dial plate 4-brace

Fig.5. Schematic of experimental device of softness testing of Anti-cut materials

3.3 Flexibility Testing

Two sides of the sample which were loaded to 5N are shown in Fig.5. The reading where the sample and the scale intersect is recorded, and then to be converted to radian. The proportion obtained by the comparison of those radian and that of the fabric with no resin on it is set as standard.

4 Results and Discussion

Results (Table 3) are adjusted according to the formula (Eq. 1, Eq. 2). The direction of samples which have the η_{max}, η_{min} and highest flexibility are in Table 4. However, actually, the direction of η_{min} in sample 2 has the highest experimental value among the η_{min} directions of all the shapes. This is because the blade did not match the linear gap precisely during testing. In order to eliminate the inaccuracy, it is still presumed that sample 4 has the highest value among the η_{min} directions of all the shapes.

$$A = \frac{E}{L} \quad . \tag{1}$$

$$Level = \frac{A}{\rho} \quad . \tag{2}$$

A=adjusted frequency E=experimental frequency L= fracture length ρ=planar density

Table 3 Results of orthogonal test of the anti-cut materials

Factor / Series	Adjusted frequency N1(max)	Adjusted frequency N2(min)	Level N1/ρ（max）	Level N2/ρ(min)	Flexibility (%)
1	0.24	0.14	0.25	0.14	20
2	1.41	0.96	1.14	0.77	24
3	0.98	0.19	0.75	0.14	27
4	1.11	0.51	0.88	0.40	27
5	0.72	0.04	0.68	0.04	17
6	1.31	0.14	0.95	0.10	11
7	3.47	0.07	2.70	0.05	11
8	2.69	0.13	1.43	0.07	11
9	0.96	0.22	1.15	0.26	23
10	1.18	0.62	0.99	0.51	12
11	0.13	0.14	0.10	0.11	10
12	0.33	0.06	0.27	0.05	34
13	0.26	0.18	0.27	0.19	25
14	1.37	0.24	1.25	0.22	14
15	0.19	0.14	0.18	0.13	55
16	0.55	0.11	0.47	0.09	55

Table 4 Specific parameters of the three majorized samples

Series	4	7	16
Shape group	quadrilateral /octagon	hexagon	quadrilateral /pentagon
Thickness /mm	0.65	0.52	0.65
Size/ proportion to standard	2	2	0.5

Table 5 Comprehensive performance evaluation

Condition	4		7		8	
	f_{min}	f_{max}	f_{min}	f_{max}	f_{min}	f_{max}
-20℃	31	185	4	65	1	3
25℃	30	60	3	180	5	26
50℃	36	118	25	179	1	45
immersed	44	66	4	81	2	20
flexibility (%)	27		11		55	
planar density	1266		1288		1178	

Sample 4, sample 7 and sample 16 were tested after immersed into water in 20°C and 50 °C in 20 min (Table 5).

It is obvious that these samples have excellent resistance to low and high temperature and also moisture. In order to evaluate the testing method we designed, samples were tested by un improved EN388-2003 standard[16] . Blade became blunt when it incised sample 16 for 100 circles. It is obvious that the anti-cut performance of samples has reached the highest level-level 5 in EN388-2003 standard[16], because those can bear at least 20 circles is qualified to be level 5.

The flexibility increased because the structure of Na-magadiite was improved (Fig. 1). Its anti-cut performance was almost the same with the planar structure which has no consecutive linear gap exist.

According to the result analysis, the influence of the shape group, size and thickness on the anti-cut performance and flexibility were discussed.

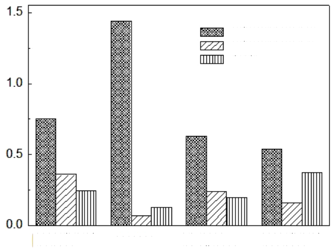


Fig.6. The anti-cut performance and flexibility of the four kinds of Shape group

4.1 Influence of the shape group on anti-cut performance and flexibility

It can be obtained from the comparison that in the η_{min} directions, the anti-cut performance of quadrilateral/octagon, big round/small round and quadrilateral/ pentagon is higher than the hexagon group (Fig. 6). While in the η_{max} direction, the anti-cut performance of hexagon is higher than that of the other three. The flexibility of quadrilateral/pentagon is the highest while that of hexagon is the lowest. This may attribute to the folded direction: the more folded direction, the better flexibility.

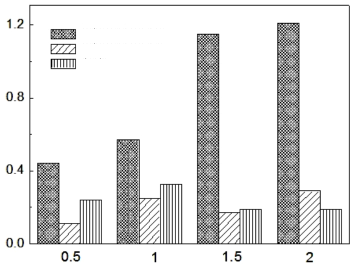


Fig.7. The anti-cut performance and flexibility of the four kinds of coating spot size ratio

4.2 Influence of the size on the anti-cut performance and flexibility

The influence can be obtained through the orthogonal test(Fig. 7). The anti-cut performance in η_{max} increase as the size increase, but the anti-cut performance in η_{min} varies a little. This is because the variation of resin coverage rate η. The flexibility decreases as the size increase.

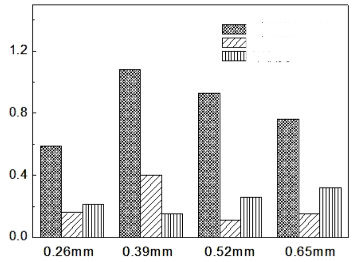


Fig.8. The anti-cut performance and flexibility of the four kinds of coating thickness

4.3 Influence of the thickness on the anti-cut performance and flexibility

The influence can be obtained through the orthogonal test(Fig. 8). Both the anti-cut performance in both of η_{max} and η_{min} direction of 0.39mm-thick sample are the best. The flexibility increase a little as the thickness increase, and this is because resin can immerse the fabric easily before curing resulted from its easy flow in thin mold when preparing thin samples.

5 Conclusion

A novel anti-cut material was prepared by simulating the structure of Na-magadiite. The influence of shape group, size and thickness on the anti-cut performance and flexibility were discussed with orthogonal test. The highest and lowest performance varies because of the different resin cover rate η. The anti-cut performance in η_{max} direction increase, but the anti-cut performance in η_{min} direction varies a little as the size increases. The flexibility of different shape groups varies because of the folded direction. It decreases as the size increases, and increase slightly in thicker samples. Moreover, due to its relatively simple process and low cost, its cost is much lower than current ones. Considering its high strength, high flexibility and low-cost, it has a prospect application in industry and daily life.

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