Mechanical Properties Test of Nano Modified Coating Material for Color Antiskid Pavement

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Abstract. For the development of the mechanical properties of better color anti-skid road surface coating material, nano MMT modified agent was added to PMMA material to modify its mechanical property. The microscopic mechanism of performance modification is analyzed. Various proportional nano MMT modified Polymethylmethacrylate (PMMA) were designed. Then tensile strength tests before and after coating materials nano modified were done by universal testing machine and preparation specimens. The results show that PMMA strength with adding MMT is significantly higher than no additive under different hardening agent ratio. Microscopic mechanism and macroscopic performance show that adding nano MMT improved the mechanical properties of PMMA.

1. Introduction

As living standard enhancement of people and the theory of humanism in road traffic, the application of "safe" and "environment" will become the two themes of future road construction. The traditional white and black two colors of pavement can't meet the needs of modern road traffic. Color anti-skid pavement earlier application in the developed countries, it is widely used in the developed countries in Europe at present[1-2]. British research survey showed that color anti-skid road is highly effective in reducing accidents. It often can reduce the accident injury by 50%. Traffic accidents in California of the United States decreased by 21% ~ 67% in concord by setting the color pavement[3]. The application of color anti-skid road also shows the tendency of growth in New Zealand, Australia, Japan and other countries in recent years. Colored pavement in China is explored in the early 1980s. In recent years, it is used more and more as a new type of revetment technology in places such as highway, road or square and is regarded as new green building materials by engineering.

Resin is the main ingredient of colored pavement anti-skid paint, alkyd resin, mainly including alkyd resin, epoxy resin, polyurethane resin, acrylic resin and high chlorinated polyethylene resin[4-5]. There are some famous product such as Advanced materials company’s product Amcoat DC4667 a two-component epoxy type non-slip coating in the United States. It is high solid content, good resistance to chemical media performance. Australia TSI-Queensland company’s product Duram Rocktuff non-slip polyurethane coating also has good skid resistance[6]. Color pavement anti-skid coating technology research in China from the 1980s, the real color pavement anti-skid coating technology was introduced into our country in 2004[7]. Compared with foreign advanced technology, the current domestic color pavement anti-skid coating research and development is still in a relatively backward stage, an urgent need is to develop new products that can be comparable to those of the international similar products.
Color anti-skid road surface is laid in the original road surface (Fig.1). Color anti-skid road surface is consist of the base course, road surface (asphalt or cement concrete pavement), adhesive layer, color non-slip aggregate protection layer.

Pavement + adhesive coating + color aggregate is now the most commonly used anti-skid road structure[8]. The laying sequence makes perfect combination of the glue with pavement and color non-slip aggregate. Because colored pavement layer is thinner, the influence of vehicle into the road surface is small[9-10]. It makes driving more smoothly. Coloured aggregate is shown in Fig.2. This paper studies its non-slip coating material.

Fig.1 Color anti-skid road surface structure  Fig.2 Colored aggregate diagram

2. Material and methods

2.1. Material

2.1.1. Nano MMT modified PMMA reaction mechanism

Polymethylmethacrylate can be abbreviated to PMMA. It is so far the most excellent material quality of synthesis transparent material and the price is cheaper. PMMA resin is avirulent environmental protection material and a colorless liquid, as shown in Fig.3. Its boiling point is 101 °C and the density is 0.940 g/cm³ [11-12]. It is the base material of adhesives for color anti-skid road and it has good chemical stability and weather resistance. The shortcoming of PMMA resin is very brittle cracking, surface strength is low[13]. Its Chemical reaction equation indicated below.

\[
\text{CH}_3 \quad \text{C} \quad \text{CH}_3
\]

\[
\text{C} \quad \text{CH}_2 \quad \text{C} \quad \text{CH}_3
\]

\[
\text{COOCH}_3 \quad \text{C} \quad \text{COOCH}_3
\]

Nano MMT is a natural mineral silicate. The main mineral component is bentonite ore. It can be widely used in the industries of high polymer material as nanometer polymer additives. It can improve the impact resistance, fatigue resistance, dimensional stability and gas barrier properties, etc. Adding nanometer materials MMT to polymethylmethacrylate adhesive can appropriately increase its bonding strength, as shown in Fig.4[14]. MMT chemical structural formula can be written as: Na_{0.7}Al{1.33}Mg_{0.7}Si_{6}O_{20}(OH)_{4} \cdot nH_{2}O. MMT mainly contains 50% to 70% SiO_{2}, 15% to 20% Al_{2}O_{3}.
Polymer PMMA gets into MMT layers to form intercalated nanocomposites. It will change the polarity between layers of MMT, increase affinity with organic molecules and make layer spacing increases that the organic monomer molecules or polymer molecules insert. Because nano MMT dispersed in the PMMA matrix, it plays a role in a uniformly distributed load and the transmission, transfer, share of the stress and blocking the crack further development. Therefore, the mechanical properties of composite materials will increase to a certain extent with the increase content of MMT. This is principle of modification of PMMA by nano MMT.

2.1.2. Two-component nano modified polymethylmethacrylate (PMMA) adhesive materials design

1) Composition design of binder with different dosage of curing agent

Polymethylmethacrylate binder is a two-component polymer materials. In construction with the other components (named hardening agent K2S2O8), it will form the final mesh structure of high polymer by making the material produces rapid secondary crosslinking reaction[15-17]. In order to develop better adhesive performance, nano MMT will be added to polymethylmethacrylate adhesives. By contrast test research of adding different proportion MMT nanoparticles and considering mechanics and economic performance, the test choice adding 3% of nano MMT together with 1%, 2%, 3%, 4%, 5% five hardening agent to do adhesive performance testing. Specific material composition design is shown in Table 1.

| Group number | MMA (g) | Curing agent | MMT(g) |
|--------------|---------|--------------|--------|
| 1            | 100     | 1            | 3      |
| 2            | 100     | 2            | 3      |
| 3            | 100     | 3            | 3      |
| 4            | 100     | 4            | 3      |
| 5            | 100     | 5            | 3      |
2) Composition design of binder material with different proportion of nano modifier

Nano modified two-component MMA binder selected curing agent is 3%. The design binder materials with different dosage proportion 1%, 3%, 5%, 9%, 12% of nano MMT modifier are shown in Table 2. The bond strength test was done to analyze the changes of nano modified two-component MMA with different nano MMT modifier dosage proportion.

Table 2. Bicomponent polymethyl methacrylate adhesives material composition design table

| Group number | MMA (g) | Curing agent (g) | MMT(g) |
|--------------|---------|-----------------|--------|
| 1            | 100     | 3               | 1      |
| 2            | 100     | 3               | 3      |
| 3            | 100     | 3               | 5      |
| 4            | 100     | 3               | 9      |
| 5            | 100     | 3               | 12     |

2.2. Test method

Bond strength of coating material before and after the nano modification is done by using universal testing machine to complete tensile test of two pieces of bond cement mortar. The size of cement mortar test block is 4 cm wide and 1 cm thick. So the cross-sectional area A is $4 \times 10^{-4} \text{ m}^2$. Tensile experiment figure is shown in Fig. 5.

![Fig.5 Tensile experiment figure](image)

3. Results and discussion

Tensile experimental results of polymethylmethacrylate with adding 3% MMT and different content of hardening agent are shown in Table 3 and Table 4.

Table 3. Tensile experiment results of polymethylmethacrylate

| Content of hardening agent (%) | 1   | 2   | 4   | 5   |
|--------------------------------|-----|-----|-----|-----|
| Force value (KN)               | 5.40| 5.38| 5.22| 5.12|
| Displacement (mm)              | 1.20| 1.29| 1.33| 1.28|

Table 4. Polymethylmethacrylate tensile experimental results by adding 3% MMT

| Content of hardening agent(%)  | 1   | 2   | 3   | 4   | 5   |
|--------------------------------|-----|-----|-----|-----|-----|
| Force value (KN)               | 6.11| 5.98| 5.78| 5.70| 6.04|
| Displacement (mm)              | 1.25| 1.33| 1.23| 1.25| 1.33|

According to the Eq. (1) and Eq. (2), bond strength can be calculated:

$$QT = \frac{F}{A}$$  \hspace{1cm} (1)

$$C = 1.8 \frac{QT}{0.7}$$  \hspace{1cm} (2)

QT - tensile strength (MPa);
F - force value (KN);
A-the cross-sectional area(㎡);
C - bond strength (MPa).
Polymethylmethacrylate adhesive strength before and after adding 3% nano MMT is calculated by Eq. (1) and Eq. (2), the result is shown in Table 5.

| Content of hardening agent (%) | 1   | 2   | 3   | 4   | 5   |
|-------------------------------|-----|-----|-----|-----|-----|
| Bond strength without nano MMT (MPa) | 34.71 | 34.59 | 34.07 | 33.58 | 32.92 |
| Bond strength by adding 3% nano MMT (MPa) | 39.28 | 38.44 | 37.16 | 36.64 | 38.83 |

Fig.6 Adhesive strength histogram of PMMA and adding 3% MMT PMMA

By Table 5 and Fig.6, polymethylmethacrylate adhesive bond strength is between 30 MPa and 35 MPa. As a whole the bonding degree decreases with the increase of hardening agent. By adding 3% of MMT, polymethylmethacrylate adhesive strength is between 35 MPa and 40 MPa. No matter how much content of hardening agent, the bond strength by adding 3% nano MMT is bigger than the bond strength without adding nano MMT materials. The bond strength reduces the colored anti-skid pavement threshing phenomenon and greatly improves the colored anti-skid pavement durability. When adding 1%, 2%, 3%, 4%, and 5% curing agent, the curing time is within 1h. With the increase content of curing agent, curing time is reduced.

Different nano modifier dosage proportion of tensile test results are shown in Fig.7. The results show that nanometer can effectively improve the bicomponent polymethyl methacrylate adhesives bond strength. By adding different proportions of MMT, bond strength after adding different proportions nano MMT increase at a rate of 4.19%, 13.54%, 19.83%, 28.41%, 19.83%. With nano MMT content increasing, the modification effect of bond strength gradually increases, however, more than 9% the effect no longer obvious. The approximate function relation between bond strength y and nano MMT content x is $y = 0.77 + 34.33x$, appropriate proportion can be chosen according to the needs of engineering calculation.
Fig. 7 Different proportions of nano MMT adhesives bond strength contrast figure

4. Conclusions
Polymethylmethacrylate adhesives with nano MMT can significantly increase the bonding strength. By adding 3% of nano MMT to polymethylmethacrylate, adhesive strength is between 35 MPa and 40 MPa which is significantly higher than that of polymethylmethacrylate adhesive bond strength 30 MPa to 35 MPa. Hardening agent can reduce the hardening time and bonding degree decrease with the increase of hardening agent. With the increase of MMT content, modification effect is enhanced. Bond strength increase gradually, after more than 9% increase bond strength effect is not obvious.

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References
[1] Xie Qianhong, Luo Yongle, Chen Xiaotian, Guo Jiehuang. The research progress of colored pavement antiskid coatings [J]. Journal of Guangdong chemical industry, 2014, 41(14) : 91-92.
[2] Wang Jing, Zhao Dasheng, Sun xiu-ying. Current situation and development trend of China’s environmental protection adhesive [J]. Chemical and glue, 2009, 31 (2) : 51-53.
[3] Wen Bin, Cao Dong-wei. Highway pavement sliding resistance and the traffic accident statistical analysis [J]. Highway traffic science and technology, 2006, 23 (8) : 72-75.
[4] Pan Zhuren. Polymer chemistry [M]. Beijing: chemical industry press, 2007.
[5] Ma Zhongna. The quality requirement and application of pavement anti-skid coating technology research [J]. Highway traffic technology: application technology edition, 2012, (2) : 89-92.
[6] Zhou Xinhua, Xu Weiping, Xia zheng-bin. Acrylic resin dispersion effect on the properties of two-component waterborne polyurethane [J]. China leather, 2004 (23) : 5-7.
[7] Wang Jian-wen. Colored antiskid material new technology application in highway research [J]. Transportation standardization, 2011, (3) : 184-186.
[8] Zhao An-ping, Thang Aiping. Color non-slip surface coating properties and applications [J]. Road construction machinery and construction mechanization, 2013, (02) : 31-34.
[9] Lv Wei-min, Li li-han. Both at home and abroad the research and application of colored pavement [J]. Journal of Shanghai municipal engineering, 1998, (02) : 53-55.
[10] Bellotti C,Bellotti F,Gloria AD.Developing a near infrared based night vision system[C].IEEE Intelligent Vehicles Symposium,2004:14-17.
[11] Gong Changsheng,Zhang Kesheng. New functional materials [M]. Beijing: chemical industry press, 2001.
[12] Zhang Shenglin, Zhao an-ping, Shang Aiping, Yu xue-mei. Current situation and the development of colored antiskid pavement [J]. *Journal of road construction machinery and construction mechanization*, 2013, (02) : 26-30.

[13] Wang Liangyan, Han Daojun, Chen Shizhou. Color pavement technology and development [J]. *Journal of transportation science and technology and economic*, 2009,52 (02) : 21-30.

[14] Chen Shiwei, Lu Xuchen, Zhang Zhimin. Preparation and characterization of poly(methyl methacrylate) reactive montmorillonite nanocomposites [J]. *Polymer composites*, 2016, 2396-2403.

[15] Ma Zhong-nan. Research quality skid coatings and application technology [J]. *Highway and Transportation Research: Application and Technology*, 2012, (2): 89-92.

[16] Luo Hai-bing. Colored pavement technical solutions and color non-slip surface design [J]. *China Municipal Engineering*, 2007, (2): 11-16.

[17] Shao Qi, Li Aiguo, Ran Meng-Jiang. International Airport Highway colored pavement design and application [J]. *Highway*, 2009, (6): 193-196.