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Process Behavior and Application of Dynamic Self – Adjusting Water – Transferring Composite Coat(小2号黑正字体，占两行)

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Abstract(外体5号方头正字体): A kind of water – transferring composite used for water saving and planting in desertification controlling was prepared. It was composed of different proportions of polyacrylamide solutions and montmorillonite coated on fibre. The micro – appearance of the coated fibre and the microstructure of the coat were described by scanning electron microscope. The water desorption characteristics of the coat were detected by thermogravimetry. The water – transferring capabilities of the coated fibre in soil with various moisture were analysed by rapid moisture meter. The results show that montmorillonite grains disperse throughout the branches of polyacrylamide. Water transfer rate is determined by spatial continuity of the grains which is caused by dominant action of polyacrylamide on montmorillonite under different water potentials of the coat. The rate increases with soil moisture decreasing. The survival rate gets higher when the coat is applied to picea asperata mast. Self – adjustment of the composite coat to soil moisture provides appropriate water to plants.

Keywords: water – transferring coat; water potential; water saving and planting; desertification controlling(外体9磅白正字体)

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动态自调节导水复合涂层的过程行为及应用(2号黑体占4行)

张增志[1]，张利梅[1]，赵　瑾[1]，李根柱[2](4号楷体占一又四分之三行)
(1. 中国矿业大学生态功能材料研究所，北京　100083)
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摘　要：制备了一种用于荒漠化治理中节水造林的动态导水复合材料。该材料是由不同比例的高吸水性树脂与蒙脱土复合于纤维支撑体表面构成涂层。用SEM分析了涂层材料的显微结构，用热分析研究了材料的吸脱附水特性，用快速水分仪测定了不同土壤湿度条件下材料的导水参数。结果表明：蒙脱土颗粒能够拆解并分散于高吸水树脂的枝状体结构中；通过树脂对蒙脱土的支配作用所产生的蒙脱土颗粒的空间连续性来确定其导水速率，该速率随土壤湿度的降低而增加；使用该材料后云杉树苗成活率得以大幅度提高；涂层材料对土壤湿度的自调节作用为植物生长提供了合理的水分条件。

关键词(小5号黑体)：导水涂层；水势；节水造林；荒漠化治理(6号书宋字体)

1　Introduction(小4号外文外挂字体Arial黑体占2行)

Desertification is a serious issue that the world is facing. Since 1990s, China's desert area has been increasing at a rate of 2 460 km^2 per year[1-2]. Ecological Restoration has become a regional problem in desertification areas; the evaporation is as high as 1 500 ~ 3 000 mm and the precipitation is generally under 300 mm in these areas. It is difficult to guarantee the plants surviving using traditional irrigation methods, which leads to groundwater reduction, large amount of water evaporation, and even unsustainable development of ecological construction.

There are many water saving and planting techniques worldwide, such as water harvesting technologies, super absorbent polymers, solid water, drip irrigation, and seep – irrigation. The water harvesting technologies are widely used in drinking water, food production, drought reforestation, the livestock industry, the transformation of saline – alkali soil, water for urban life and industrial production, and water shortage problems of agro – forestry[3-6]. In our country, simple land preparation methods such as level step, level trench, and fish – scale pits are used to improve the survival rate of afforestation of catchments, but the effect is of no significance. The aquasorbs absorb water through special molecular structure. They have strong retention[7-9], but the absorbed water can not be released with simple physical methods[10]. 98% of solid water is

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water. Water is released slowly through the soil microorganisms. The aquasorb and the solid water can't guarantee the plants in the desert to survival because of high water absorption ratio, short water holding time and salt – tolerance. Drip irrigation technology can guarantee long – term water supplying, but it isn't applicable to plant trees in the desert because of high costs[11]. Other technologies such as container nursery[12] and ABT[13] are not suitable in the desert because they need plenty of water. (9.5磅书宋字体)

Researchers of Research Institute of Ecological and Functional Materials in China University of Mining and Technology have developed a kind of Water Storage and Controlled – release Film (WSCF), which can be used in forestation in arid area or semi – arid area[14]. WSCF is a kind of composite film prepared by compounding functional water – transferring coated fibre and environmentally friendly polymer material. When WSCF is packed with water and embedded in soil around tree roots, it forms a "small reservoir" in the soil to meet the need of plant growth. The water – transferring coated fibre is a kind of natural plant fibre coated with mixed colloid composed of sop organic macromolecule (polyacrylamide) and montmorillonite grain. It can transfer water automatically according to the water requirement of the plants.

There are few rainfalls in desertification areas, which leads to high cost and difficulty in promotion of the above techniques. Under this condition, we present a water – transferring composite used for water saving and planting in desertification controlling. The components of the composite are determined to study their water – transferring performance. The water transferring mechanism of the presented fibre is also researched in the paper.

2 Experimental methods and results

2.1 Experimental materials

(9.5磅外文外挂字体Arial黑体占1行)

The coat was composed of the absorbent organic polymer (Polyacrylamide), the ultra – fine montmorillonite grain and distilled water. Different proportions of polyacrylamide and montmorillonite were adopted to prepare the coat and their water – transferring performances were measured. The component of the coat is shown in Table 1.

Table 1 Component of the coat(6号方头正字体)

Samples	Polyacrylamide(g) : Montmorillonite(g)	Composite(g) : Water(ml)
M1	0.1 : 18	18.1 : 100
M2	0.1 : 14	14.1 : 100
M3	0.1 : 10	10.1 : 100

2.2 Experimental methods

The integrated thermal gravimetric analyzer (Perkin Elmer Diamonds Ⅱ) was used to analyze the desorption of the coat. The micro – appearance of the coated fibre and its microstructure was described by the environment scanning electron microscope. The water – releasing characteristics in soil of various moisture were analyzed by fast water – equipment (M30). Water – transferring coated fibre was compounded with polymer to form composite film. The fibre density of composite film was 10 bundles/25 cm^2. The composite film was made in shape of bag and packed with water. Instrument for quick measuring moisture M30 was used to determine the ratio of water loss of the composite film. The determination time was 30 min and the temperature was 65 ℃.

The composite film packed with water was put beside the root of Picea asperata Mast in an experiment area of Tongliao Forestry Research Institute to measure the soil moisture around root of Picea asperata Mast.

2.3 Experimental results

The different coated fibres were fixed in the environmentally friendly films, and their water loss rate at different temperatures was measured by the fast water equipment. The result is shown in Fig. 1. The water loss rate of M1 and M3 change obviously, but that of M2 doesn't. It is comparatively stable, which means that M2 isn't sensitive to the temperature.

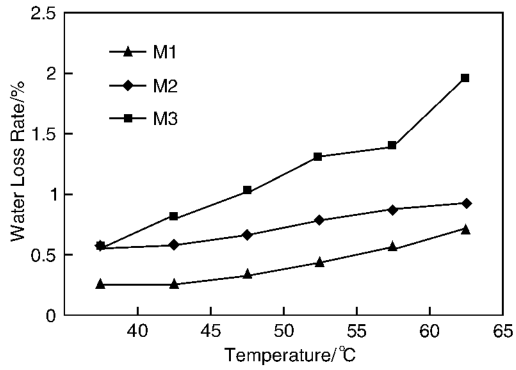

Fig. 1 Water loss rate at different temperatures

(6号书宋字体)

The films were put into the draughty desert soil with moisture of 3%, 6%, 9% and 12% respectively after packed water. The water loss rate is shown in Fig. 2. It is seen that the water loss rate in low moisture soil is higher than that in high moisture soil. M2 still shows stable performance under this condition. The coated fibre can make self – adjustment of its water transfer velocity to the different moisture of the soil.

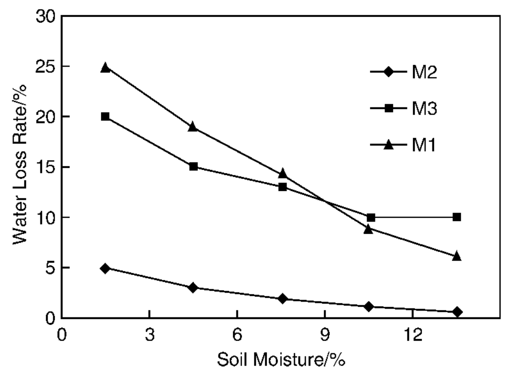

Fig. 2 Water loss rate in soil with different moisture

The results of composite films, M1, M2 and M3, put beside the root of picea asperata mast, are shown in Fig. 3.

Fig. 3 shows the soil moisture 5 cm, 10 cm and 15 cm away from the root of picea asperata mast. They all decrease gradually in ten days, but the moisture of the soil which is 5 cm away from the root is higher than the other two places, which illuminates that in the coat has transferred water to the soil near the root. The moisture of the soil far off the root is low because the packed water is transferred slowly by the coat. This guarantees that it can provide water to Picea asperata Mast continually.

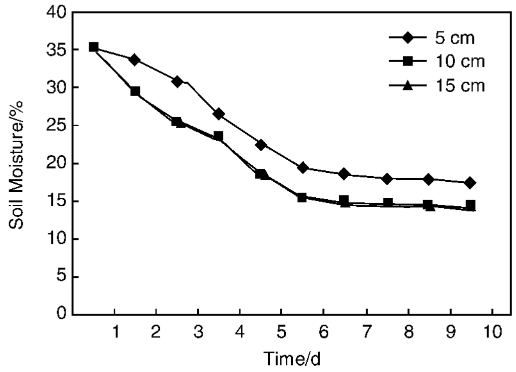

Fig. 3　Soil moisture at different time

3　Analysis and discussion

3.1　Performance of materials

Montmorillonite is a kind of natural layered silicate mineral with 2 : 1 type structure, as shown in Fig. 4, and it can absorb a great deal of water because there are adsorption exchangeable cations between the layers and they are usually in the state of hydration which causes to expand the distance of the layers. Fig. 5 shows the thermal performance of montmorillonite. It indicates that the water in the layers is mainly physical water, almost released at 20 ~ 140 ℃. So the water can be transferred through the layers easily.

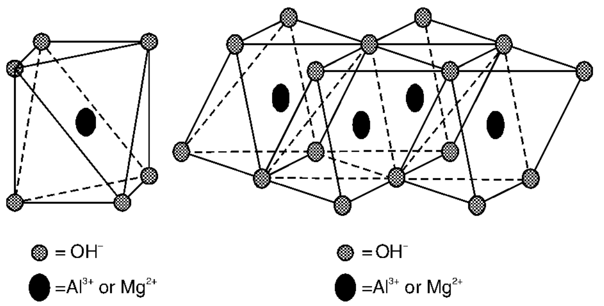

Fig. 4　Structure of montmorillonite

Polyacrylamide is a mildly binder crosslinked polyelectrolyte with three - dimensional network structure. There are a large number of hydrophilic groups on its macromolecular chains, so that it can absorb a great deal of water relying on its internal three - dimensional networks and causes swelling. The behavior of water adsorption is not the capillary adsorption, it is physical adsorption of high polymer net. So the water in polyacrylamide is still ordinary water, which is just restricted by the net structure. The desorption of polyacrylamide and swelled polyacrylamide is shown in Fig. 5. It is seen that the swelled polyacrylamide loses about 90% of the water in the process of heating while the polyacrylamide just loses about 20%, which means there is much water existing in the net structure of swelled polyacrymide. The structure of montmorillonite is not destroyed when the absorbed water is released in the heating process, which indicates that the releasing process is reversible.

As shown in Fig. 6(a), the particles of montmorillonite tend to minimize in the solution and are fully dispersed in the network space of the polyacrylamide. This is because that the polyacrylamide is a kind of multi - hydroxy water - soluble polymer and has strong compatibility with the montmorillonite. So the platelets of the montmorillonite are fully dispersed in the solution to form a great deal of pores to conserve and release water when the polyacrylamide dissolves fully in the montmorillonite solution. The temperature in this process is lower because the bond strength between the absorbed water and the montmorillonite is infirmed. The micro - appearance of the fibre is shown in Fig. 6(b). We can see that the coat covers the surface of the natural fibre evenly.

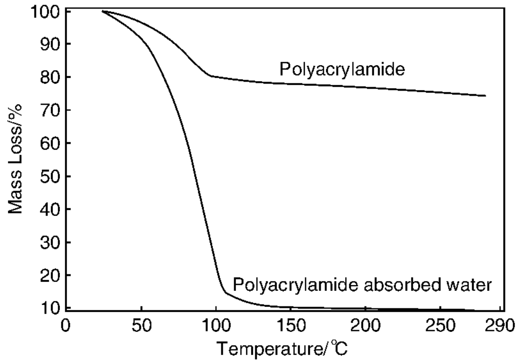

Fig. 5　TG curves of the polyacrylamide

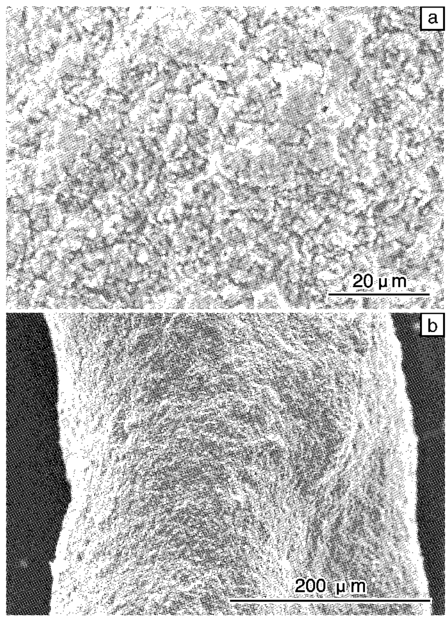

Fig. 6　Microappearance of the coat structure (a) and coated fibre (b)

3.2　Transferring mechanism

Polyacrylamide is a mildly binder crosslinked polyelectrolyte with three - dimensional network structure. There is not only physical adsorption but also chemical adsorption in its water adsorption process. The long chains of the polymer twine together to form a netlike structure before contacting with water. But the net expanded under the function of the hydration between the water - tendency groups and the water molecules after it absorbed water. This causes different ion concentration in and out of the net. It results in the osmotic pressures in the net. So the water infiltrates into the coat through its structure. The swelled polyacrylamide is shown in

Fig. 7 (a).

Montmorillonite is a kind of hydrophilic abio – mineral. It has a certain degree of absorbent performance which is caused by the strong hydration of its activity centre.

It isn't simple physical admixture between montmorillonite and polyacrylamide. There are three kinds possibly: filler type, surface graft polymerization and structured. A proper cross – linked admixture can be produced to transfer water if the proportions are appropriate, as shown in Fig. 7 (b).

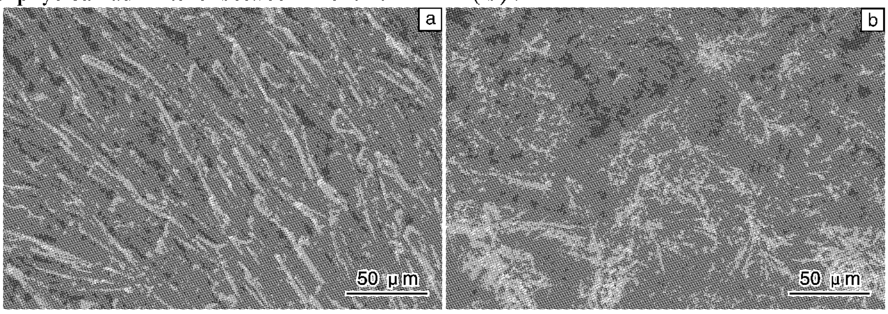

Fig. 7 SEM micrographs of the coat structure (a) swelled coat and (b) dry coat

3.3 Transfer mode

Fig. 8 shows water – transferring mode of the coat. The film which has been packed some water is put in the desertification soil or the draughty soil, one side of the fibre in the packed water, the other side in the droughty soil, so that water can be transferred to the soil through the coated fibre due to different water potentials on the two sides of the fibre. The transferring mechanism is shown in Fig. 8. On the water side, the polyacrylamide swells because of high water potential, the montmorillonite grains are in the state of bridge break, so water is transferred relying on adsorption – desorption function of the polyacrylamide (see Fig. 9(a)). While on the other side, the montmorillonite grains are in the state of bridge connection because of the low water potential, water is transferred by these grains(see Fig. 9(c)). The transient state is shown in Fig. 9(b). Since the adsorption – desorption energy barriers are different between the polyacrylamide and the montmorillonite grains, different water potentials are formed to transfer water. Therefore, we can confirm the water potential by designing the proportion of the polyacrylamide and the montmorillonite in the coat to realize reasonable soil moisture.

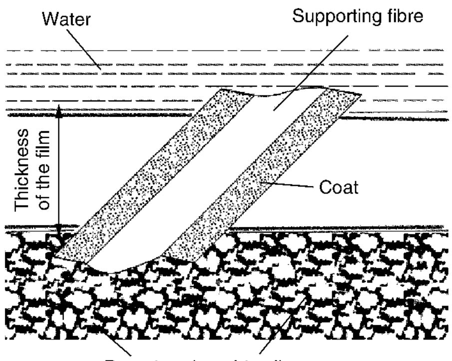

Fig. 8 Water transferring diagram of the coat

4 Conclusions

(1) Montmorillonite grains tend to minimize in the aqueous solution of the polyacrylamide and are fully dispersed in the network space of the polyacrylamide.

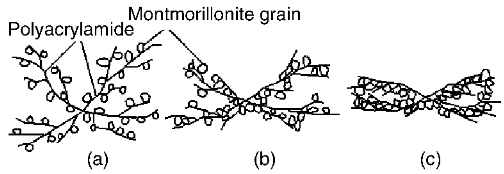

Fig. 9 Water – transferring mechanism diagrams of the coat: (a) high water potential, (b) transient state, and (c) low water potential

(2) Different energy barriers are formed due to different water potentials at both sides of the coated fibre, which forms water potential gradient to realize water transfer.

(3) The water transfer rates of the coated fibre can adjust itself to the different soil moisture to meet the water requirement of the plants in time.

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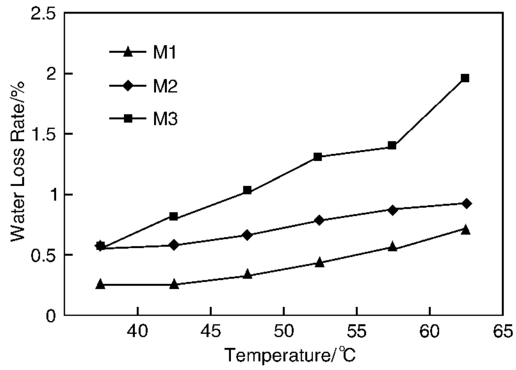

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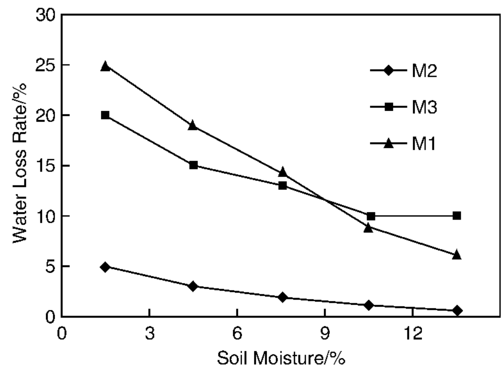

Fig. 2 Water loss rate in soil with different moisture

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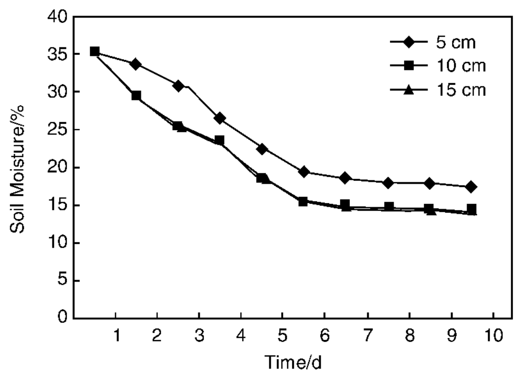

Fig. 3 Soil moisture at different time

Fig. 3 shows the soil moisture 5 cm, 10 cm and 15 cm away from the root of picea asperata mast. They all decrease gradually in ten days, but the moisture of the soil which is 5 cm away from the root is higher than the other two places, which illuminates that in the coat has transferred water to the soil near the root. The moisture of the soil far off the root is low because the packed water is transferred slowly by the coat. This guarantees that it can provide water to Picea asperata Mast continually.

3 Analysis and discussion

3.1 Performance of materials

Montmorillonite is a kind of natural layered silicate mineral with 2: 1 type structure, as shown in Fig. 4, and it can absorb a great deal of water because there are adsorption exchangeable cations between the layers and they are usually in the state of hydration which causes to expand the distance of the layers. Fig. 5 shows the thermal performance of montmorillonite. It indicates that the water in the layers is mainly physical water, almost released at 20 ~ 140 ℃. So the water can be transferred through the layers easily.

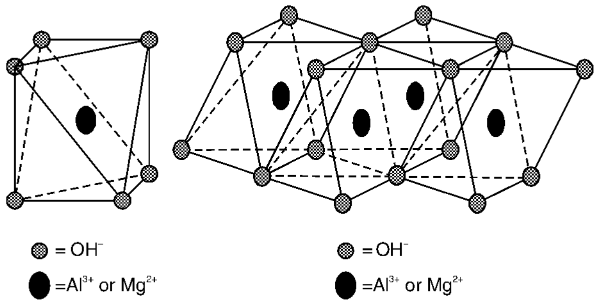

Fig. 4 Structure of montmorillonite

Polyacrylamide is a mildly binder crosslinked polyelectrolyte with three - dimensional network structure. There are a large number of hydrophilic groups on its macromolecular chains, so that it can absorb a great deal of water relying on its internal three - dimensional networks and causes swelling. The behavior of water adsorption is not the capillary adsorption, it is physical adsorption of high polymer net. So the water in polyacrylamide is still ordinary water, which is just restricted by the net structure. The desorption of polyacrylamide and swelled polyacrylamide is shown in Fig. 5. It is seen that the swelled polyacrylamide loses about 90% of the water in the process of heating while the polyacrylamide just loses about 20% , which means there is much water existing in the net structure of swelled polyacrymide. The structure of montmorillonite is not destroyed when the absorbed water is released in the heating process, which indicates that the releasing process is reversible.

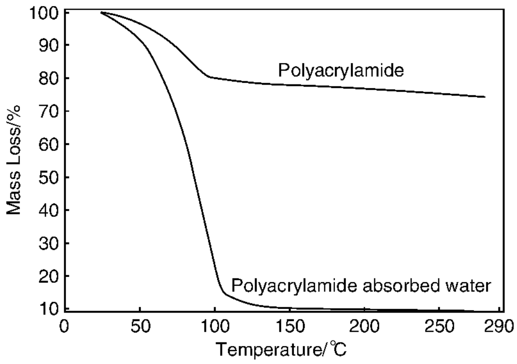

Fig. 5 TG curves of the polyacrylamide

As shown in Fig. 6 (a), the particles of montmorillonite tend to minimize in the solution and are fully dispersed in the network space of the polyacrylamide. This is because that the polyacrylamide is a kind of multi - hydroxy water - soluble polymer and has strong compatibility with the montmorillonite. So the platelets of the montmorillonite are fully dispersed in the solution to form a great deal of pores to conserve and release water when the polyacrylamide dissolves fully in the montmorillonite solution. The temperature in this process is lower because the bond strength between the absorbed water and the montmorillonite is infirmed. The micro - appearance of the fibre is shown in Fig. 6(b). We can see that the coat covers the surface of the natural fibre evenly.

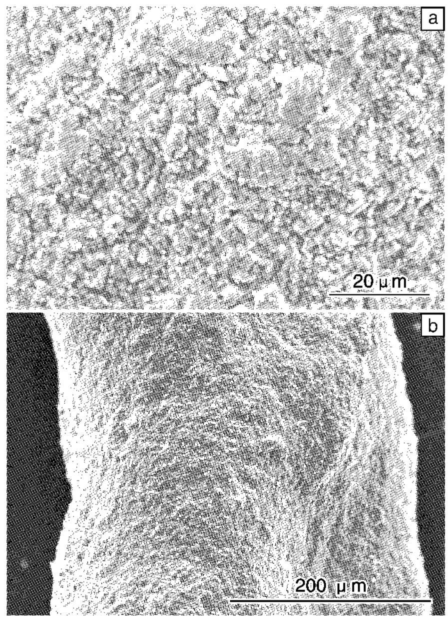

Fig. 6 Microappearance of the coat structure (a) and coated fibre (b)

3.2 Transferring mechanism

Polyacrylamide is a mildly binder crosslinked polyelectrolyte with three - dimensional network structure. There is not only physical adsorption but also chemical adsorption in its water adsorption process. The long chains of the polymer twine together to form a netlike structure before contacting with water. But the net expanded under the function of the hydration between the water - tendency groups and the water molecules after it absorbed water. This causes different ion concentration in and out of the net. It results in the osmotic pressures in the net. So the water infiltrates into the coat through its structure. The swelled polyacrylamide is shown in Fig. 7 (a).

Montmorillonite is a kind of hydrophilic abio - mineral. It has a certain degree of absorbent performance which is caused by the strong hydration of its activity centre.

It isn't simple physical admixture between montmorillonite and polyacrylamide. There are three kinds possibly: filler type, surface graft polymerization and structured. A proper cross - linked admixture can be produced to transfer water if the proportions are appropriate, as shown in Fig. 7 (b).

3.3 Transfer mode

Fig. 8 shows water - transferring mode of the coat. The film which has been packed some water is put in the desertification soil or the draughty soil, one side of the fibre in the packed water, the other side in the droughty soil, so that water can be transferred to the soil through the coated fibre due to different water potentials on the two sides of the fibre. The transferring

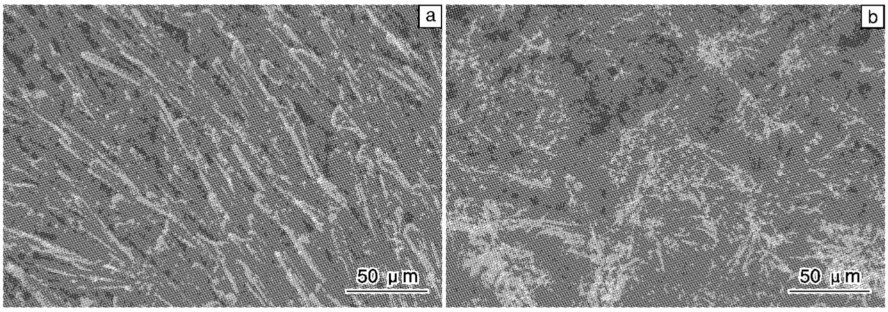

Fig. 7 SEM micrographs of the coat structure (a) swelled coat and (b) dry coat

mechanism is shown in Fig. 8. On the water side, the polyacrylamide swells because of high water potential, the montmorillonite grains are in the state of bridge break, so water is transferred relying on adsorption – desorption function of the polyacrylamide (see Fig. 9(a)). While on the other side, the montmorillonite grains are in the state of bridge connection because of the low water potential, water is transferred by these grains (see Fig. 9(c)). The transient state is shown in Fig. 9(b). Since the adsorption – desorption energy barriers are different between the polyacrylamide and the montmorillonite grains, different water potentials are formed to transfer water. Therefore, we can confirm the water potential by designing the proportion of the polyacrylamide and the montmorillonite in the coat to realize reasonable soil moisture.

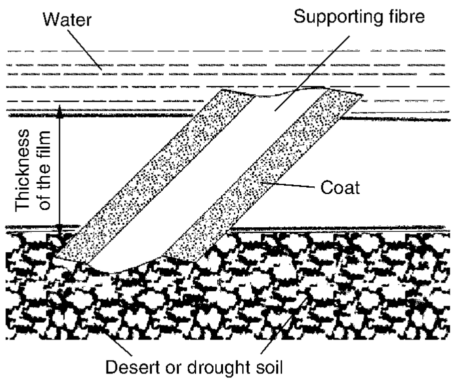

Fig. 8 Water transferring diagram of the coat

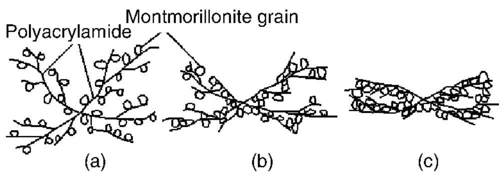

Fig. 9 Water – transferring mechanism diagrams of the coat: (a) high water potential, (b) transient state, and (c) low water potential

4 Conclusions

(1) Montmorillonite grains tend to minimize in the aqueous solution of the polyacrylamide and are fully dispersed in the network space of the polyacrylamide.

(2) Different energy barriers are formed due to different water potentials at both sides of the coated fibre, which forms water potential gradient to realize water transfer.

(3) The water transfer rates of the coated fibre can adjust itself to the different soil moisture to meet the water requirement of the plants in time.

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