A CASE STUDY ON APPLICATION OF GEOSYNTHETIC CLAY LINER IN CANAL LINING IN HETAO IRRIGATION AREA, INNER MONGOLIA

ETUDE DE CAS SUR L'APPLICATION DES REVETEMENTS D'ARGILE GEOSYNTHETIQUE DANS LES CANAUX D'IRRIGATION DANS LA REGION D'IRRIGATION HETAO EN MONGOLIE INTERIEURE

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ABSTRACT

Hetao irrigation area is one of the three largest irrigation areas in China and has a huge potential for water saving and agricultural development. However, the irrigation water using efficiency is only 0.42 due to heavy leakage loss in the canal system. The low irrigation efficiency is one of the main constraints to further develop irrigated agriculture. As a new material, Geosynthetic Clay Liner (GCL) could effectively reduce the canal seepage with the advantages of self-healing capability and good flexibility to suit the seasonal freezing condition in cold area. To investigate its performance in the field, three kinds of GCL were applied in different canal levels in Hetao irrigation area. A series of laboratory experiments were also conducted to investigate the performance of GCL under different environmental conditions. GCLs were applied in main canals, sub-main canals, lateral canals and branch canals in Hetao irrigation area. The research results showed that hydraulic conductivity(HC) of three kinds of GCL reduced from 6×10^{-9} to 2×10^{-12} cm s^{-1} in the first year and from 1.1×10^{-6} to 1.6×10^{-8} cm s^{-1} in the third year. GCLs could be applied in the canals of different hierarchical order. Comparing with canal lining using concrete blocks, the application of GCLs could significantly reduce the cost of canal lining by 50%. Therefore, there exists a great potential to use GCLs as canals lining materials in North and Northwest China.

Key words: *GCL; Canal lining materials; Hetao irrigation area.*

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RESUME

La région d'irrigation Hétao est l'une des trois principales régions d'irrigation en Chine et possède un potentiel énorme de conservation d'eau et de développement agricole. Cependant, l'efficience d'utilisation de l'eau d'irrigation est seulement de 0,42 en raison de la perte d'infiltration dans le système de canal. La faible efficience d'irrigation est l'une des contraintes du développement de l'agriculture irriguée. En tant qu'un nouveau matériau, le revêtement d'argile géosynthétique (GCL) peut efficacement réduire l'infiltration du canal avec une bonne flexibilité pour répondre à la condition saisonnière de la zone froide. Afin d'étudier sa performance sur le terrain, trois types de GCL ont été appliqués aux différents niveaux du canal d'irrigation dans la région d'irrigation Hétao. Une série d'expérimentations de laboratoire ont également été menées pour étudier la performance de GCL dans différentes conditions environnementales. Le GCL a été appliqué dans les canaux principaux, les canaux secondaires et les canaux primaires de la région d'irrigation Hétao.

Les résultats de recherche ont montré que la conductivité hydraulique (HC) de trois types de GCL réduit de 6×10^{-9} à 2×10^{-12} cm s^{-1} dans la première année et de $1,1\times10^{-6}$ à $1,6\times10^{-8}$ cm s^{-1} dans la troisième année. Le GCL pourrait être appliqué dans les canaux de l'ordre hiérarchique différent. En comparaison avec le revêtement des canaux en béton, l'application du GCL pourrait réduire de 50% le coût du revêtement du canal. Donc, il existe un grand potentiel à utiliser le GCL en tant que matériau de revêtement du canal au nord et au nord-ouest de la Chine.

Mots clés : *GCL, matériaux de revêtement du canal, région d'irrigation Hétao.*

1. INTRODUCTION

Hetao irrigation area is one of the three largest irrigation areas in China. It is located in the western part of Inner Mongolia Autonomous Region. The average annual water intake of the irrigation area is 520,000,000 m^3 from the Yellow River by gravity with the irrigated area of 574,000 hm^2. It is an important base for grain, oil, sugar, vegetables, and fruits production in Inner Mongolia.[1-2]

Owing to the convenience of irrigation by diverting water from Yellow River by gravity this area has a huge potential for agricultural development. There are seven levels of fixed canals in the irrigation system, namely general main canal, main canals, sub-main canals, branch canals, lateral canals, sub-lateral canals and field canals[3-4]. The number and length of canals are summarized in Table 1.

Table 1 the number and length of canals in Hetao Irrigation Area

Level of canals	Number	Total length (km)
General main canal	1	180
Main canals	48	1069
branch, lateral, field, sub-lateral	86,000	50,000

In the Hetao Irrigation Area the irrigation water use efficiency is only 0.42 due to heavy seepage in canal systems and leakage losses in field. The concrete blocks have been used as lining material to reduce seepage loss for a long time in the area. However, the following problems existed with the concrete lining materials in the area due to longer freezing period and the shallower groundwater with depth of 1.2 to 2.5 m: (i) in order to prevent frozen damage, complicated and expensive lining structures have to be adopted with an insulating layer, plastic membrane, cushion layer, and a concrete lining block; (ii) the maintenance costs usually reached as high as 10% of total investment after 5 years operation; (iii) The construction period for canal lining is very short, only about 30 days in April because of cold winter and irrigation requirement from beginning of May to early November. The complicated structure by adopting concrete lining materials resulted in longer construction period and poor quality.

Geosynthetic Clay Liner (GCL) is a new synthetic bentonite composite material with high-expansion sodium bentonite filled between composite geotextile and nonwoven fabrics. There are many fiber spaces in GCL produced by needle-punch, which prevent bentonite particles from moving in one direction.[5-6] The high-density gel layer is formed by bentonite expanding with water, which can effectively solve water leakage problem. Owing to good flexibility, self-healing capabilities and anti-dry cycle capability GCL has been widely used for seepage control in underground infrastructure construction, such as waste landfill in environmental engineering, artificial lakes, oil depots, and chemical yards etc. [7-8] The new materials have been tested for many years, but the local users were not satisfied with the results. by This paper summarized the research and pilot study of using Geosynthetic Clay Liner as new canal lining material in Hetao Irrigation scheme.

2. MATERIALS AND METHODS

2.1 Materials

Three kinds of GCL samples were tested as listed in Table 2.

Table 2 The tested three GCL samples

samples	**CEC (Mmol kg^{-1})**	**Particle distribution (%)**				
		2.0~0.25 mm	**0.25~0.05 mm**	**0.05~0.02 mm**	**0.02~0.002 mm**	**<0.002 mm**
No. 1	74.40	3.23	16.57	10.10	20.20	49.40
No. 2	75.50	1.31	8.39	10.10	20.20	60.00
No. 3	93.0	4.43	5.27	0	20.2	70.10

Two kinds of GCL (No. 1 and No. 2) were produced by South Korea and No. 3 GCL was produced in China. The basic structures of the three kinds of GCL were the same. The three kinds of bentonite samples were all sodium montmorillonite. The No. 3 GCL has the highest cation exchange capacity of 79.79 mmol kg^{-1}, and No. 1 and No. 2 GCL are with cation exchange capacity of 67.22 and 69.95 mmol kg^{-1}. The basic physical properties and technical parameters of the three kinds of GCL are shown in Table 3.

Table 3 the basic physical properties and parameters of the selected GCL samples

Materials	Expansion coefficient (cms^{-1})	Expansion degree ($ml.2g^{-1}$)	Thick-ness (mm)	Weight ($kg.m^{-2}$)	Water pressure (m)	Elongation (%)	HDPE roll force (N)
1#	2×10^{-12}	23	6.6	6.1	≥70	23	75.0
2#	1.5×10^{-10}	19	6.5	6.2	≥70	23	75.0
3#	6×10^{-9}	24		4.0	≥40	10	

2.2 Experimental design

2.2.1 Field experiments

To obtain extensively representative experimental results, three kinds of GCL were placed in different level of canals in Hetao irrigation area.

Main canals: Four experimental treatments were designed. Three kinds of GCL were laid directly on the renovated canal slopes in each treatment. Different protective layers were placed to cover GCL, respectively, as precast slab curing agent protection, cast-in-situ solidified mud protection, bottom bare and top spraying solidified slip, and all exposed. There are 12 experimental treatments in total.

Sub-main canals: Four experimental treatments were designed and tested. Three kinds of GCL were laid directly on the renovated canal slopes in each treatment. Different GCL protective layers were placed as cast-in-situ solidified mud, cement mortar, solidified slip on the outer surface, covering nature soil with 60 cm thickness and all bare laying, as well as the original concrete lining section (no insulating layer) as a control treatment. There were13 experimental treatments in total.

Branch canals: Three experimental treatments were designed and tested. Three kinds of GCL were placed directly on the renovated canal slopes in each treatment. Different treatments were respectively as precast slab curing agent protection outside the clay liner, cast-in-situ solidified mud protection, and bare lying, as well as the original canals upstream as control section. There were 10 experimental treatments in total.

Lateral canals and sub-lateral canals: Two experimental treatments were designed and tested. Three kinds of GCL were placed in each treatment. Two treatments were respectively as cast-in-situ solidified mud protection outside the clay liner and bare lying. There were six experimental treatments in total. For the sub-lateral canals, only one experimental treatment was designed as covering a 30 cm protective layer of nature soil on GCL.

2.2.2 Laboratory experiments

The field samples of GCL were collected from different level of canals in Hetao irrigation area to investigate the effects of environmental factors on the performance of GCL. (1) Effect of water quality on impervious performance of GCL. Three kinds of GCL samples were collected from field canals applied with GCL to investigate the effect of water quality on the permeability coefficient of GCL. (2) Comparisons of the aging resistance of GCL. Three kinds of aging accelerating tests were used to investigate effects of aging accelerating treatments on the mechanical properties of GCL, respectively as high–low temperature cycling, UV lighting, and cement slurry soaking.

3. RESULTS AND DISCUSSION

3.1 The effect of water quality on hydraulic conductivity(HC) of GCLs

The effect of water quality on HC is determined by concentration of ions, and equilibrium time. The influence of high valence cations is greater than that of low valence cations. Although the salinity of the Yellow River water is relatively low, the Ca^{2+} and Mg^{2+} are dominant amounting to 41.2% of the total cations. Therefore, the quality of Yellow River water has an effect on HC of GCL.

Test samples of GCL were taken from the canals site in Hetao areas to test the effect of ions on permeability of GCLs. After three years of practical application, HCs of the three GCLs taken from the Yonggang sub-main canal site are 1.6×10^{-8} cm s^{-1}, 1.1×10^{-6} cm s^{-1}, and 1.5×10^{-7} cm s^{-1} for GCLs 1, 2 and 3 respectively, which exceeded by 10, 3000 and 114 times compared with the controls. According to standards of the PRC “SL 18-24 canal anti-seepage engineering technical specifications,” the maximum water permeability rate allowed in concrete panels is between 0.06 and 0.17 m^3/m^2.d. Hence, even if the HC of GCL increases to 1.1×10^{-6} cm s^{-1}, it still meets the anti-seepage requirements.

In the Yellow River water, higher concentration of Ca^{2+} and Mg^{2+} replacing Na^{+1} ions in the bentonite is the mechanism for the increase in HC of GCLs. This reaction decreases Na^{+1} ions in the bentonite, which, in turn, reduces its swelling capacity and results in increased permeability. Fig.1 shows the relationship between the usage time of the three GCLs and Na^{+1} ions exchange capacity, indicating HC of the GCLs is significantly reduced in one year, and tends to be at steady state in two years. Filtration loss is an important index of GCLs permeability. Higher filtration loss means worse swelling property and higher permeability and vice versa. The filtration loss and usage time is opposite to that of former and increases with usage time, but also to tend to be at steady state in to be at steady state in two years (Fig.2).

In Hetao irrigation area, water conveyance time in the sub-main canals usually are over 100 days every year. That means cation exchange reaction between bentonite and water has reached over 300 d after three years. It is assumed that the HCof GCLs increases to 1.1×10^{-6} cm s^{-1} that is close to steady value.

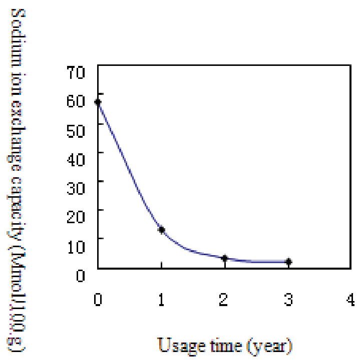

Fig. 1 the relationship between sodium ion exchange capacity and usage time

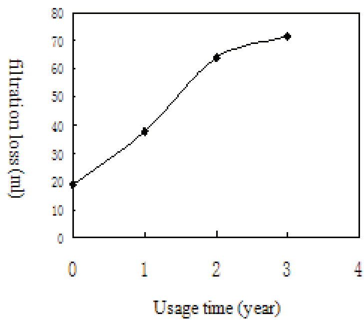

Fig. 2 the relationship between filtration loss and usage time

3.2 Testing on the aging resistance of GCLs

Three years testing showed that GCL 1 is least affected by aging, GCL 3 is most affected, and GCL 2 lies in between. The tested results agree with the original mechanical properties of the three materials. GCL 1 has the highest mechanical index with the best aging resistance property, GCL 2 ranks second and GCL 3 has the lowest mechanical index value and lowest aging resistance property.

(1) The effect of highlow temperature on the mechanical index of GCLs

The three samples were exposed to aging at high temperature of 60 °C for 72 h and the mechanical indexes of No.3, No.1, and No. 2 GCL reduced by 45.64%, 34.27%, and 35.75%, respectively. The mechanical properties of three GCLs deceased by 18.68%, 19.30%, and 10.96%, respectively, when exposed to low temperature of - 40 °C for 72 h. The extent of decrease in index for high-temperature aging is about three times to that of low temperature aging. Generally, the mechanical indexes decreased with an increase in the cycles of high–low temperature. However, the decease in the three samples is different. The mechanical indexes of No.3, No.1 and No.2 GCL reduced by 18.56%, 14.59%, and 17.64%, respectively, after 5 cycles. When cycles were increased from 5 times to 10 times the mechanical indexes of No.3 GCL and No. 2 GCL were reduced by 24.20% and 19.07%, and the mechanical index of No. 1 GCL only reduced by 5.9%. The mechanical index of No. 3 GCL reduced by 19.01%, No. 2 by 32.73%, and No. 1 by 6.7% when cycling increased from 10 times to 15 times. According to the regression analysis, the indexes of No. 3 GCL and No. 2 are 23.24 and 28.98, respectively, after 25 cycles of high–low temperature, both of which still exceed 10% the mechanical index of controls.

(2) The effect of UV on the mechanical property of GCL

UV radiation aging has relatively large effects on the mechanical properties of GCLs. After 1200 h UV radiation, the mechanical indexes of No.3 GCL, No.1, and No. 2 reduced by 49.17%, 32.42%, and 39.65% which are similar to that of 72 h high-temperature aging. This indicated that lighting has a bigger effect on GCL lifespan and the GCLs used as lining materials on the canals should be covered by protective materials such as cement slurry or earth.

(3) The effect of cement slurry on the mechanical indexes of GCLs.

The test on GCLs soaked in cement slurry was conducted in order to evaluate the effect of cement slurry used as external protective layer to anti aging. The mechanical indexes of the three GCLs reduced significantly when soaked in the cement slurry for one month. No.3 reduced by 37.4%, No.2 by 38.70%, and No.1 by 48.5%. Among the three GCLs, the mechanical indexes of No. 1 decreased most significantly because the plastic membrance was eroded by the chemical composition in cement. The protective layer layers of GCLs are generally polypropylene fiber or acrylic fiber; when soaked in cement, the alkaline in cement eroded, and resulted in the decrease of mechanical properties of GCLs.

3.3 The effect of GCL on ground temperature and frost heaving amount

GCL applied in canals can reduce the ground temperature of canal, and the reduction is more significant when closer to ground surface. The ground temperature at surface on shady slope is lower by 6 °C than the control. In the 20 cm soil layer, , The ground temperature of the upper and lower soil layer increases respectively by 0.9 °C and 1.3 °C on average, as well as the ground temperature of the upper soil layer on sunny slope increases by 0.2 °C on average.

Figures 3 and 4 show the frost melting photos of concrete lining and GCL, respectively. After frost melting, the surface of the concrete lining cracked due to its poor resiliency, as well as the surface of GCL is smooth owing to good flexibility and self-healing capabilities.

Fig. 3. the concrete lining destroyed by freezing-thawing and frost-heaving

Fig. 4. the canal slopes applied with GCl after the freezing-thawing cycle

There is no frost damages observed in canals applied with GCL during two freezing-thawing cycles. Therefore, GCL is a kind of waterproof materials with good flexibility and adaptability, especially the frost resistance of which is significantly better than concrete lining.

3.4 The effect of GCL on the stability of canal side slope

GCL applied in side slopes of different canals could play an important role in enhancing slope stability. The side slope of Changji main canals and Yonggang sub-main canals remained stable after three years of operation, with design flow of canal as 35 $m^3 s^{-1}$ and 20 $m^3 s^{-1}$, respectively. However, the treatment of GCL covered by 60 cm natural soil in Yonggang sub-main canal appeared to damage the GCL and the side slope slumped. The soil washed away by flowing water resulted in destroying the stability of GCL applied in the side slope. Figure 5 shows the damage of GCL applied in side slope of Yonggang sub-main canal with 60 cm natural soil cover after three years of operation.

Figure 6 shows the stability of side slopes applied with GCL in Yonggang branch canal. The side slopes of Yonggang branch canal applied with GCL directly are smooth and remained stable after three years of water flowing. This indicates that GCL directly applied on the canals could remain the side slopes stable, including various treatments of main canals, sub-main canals, branch canals, and lateral canals.

Fig. 5. the stability of side slopes applied with GCL in Yonggang sub-main (treatment of nature soil covered)

Fig. 6. the stability of side slopes applied with GCL in Yonggang branch canal

3.5 Economic analysis

(1) Direct cost

GCLs used as lining materials could reduce construction procedures and cost, such as plastic membranes, thermal insulation layer, and cushionlayers (for smoothness). The investment of three GCLs if lined in canals with larger section such as Yonggang sub-main canal was decreased by 50%–60% per square metercompared with concrete panel lining. Adding external protective layer increased about 10% cost that is saving 40-50% in total investment per square meter compared with concrete panel.

For canals with smaller cross -section such as branch and lateral canals, the decrease in cost was relatively lower. In the branch canals, investment in No.1 and No.2 is reduced by 23%–41% compared with a precast concrete panel. On the lateral canal, the costs reduced by 12%–23%. For sub-lateral and field canals, GCLs as lining is not cost effective.

(2) The construction procedure of GCL is relatively simple. If canals side slope is filled with earth, tamping is needed before laying the GCLs. Only smoothing the slope surface is needed before layingif the slope is undisturbed earth.The construction procedures for concrete panels are very complicated, including six processes involved: building the concrete fortified wall withstanding frozen swelling, thermal insulation layer, plastic membrane, cushion layer, laying lining panels, and filling seams , Approximately 1 m earth digged and drainage are needed when building the concrete fortified wall.Digging and drainage are very difficulty due to frozen earth and shallower ground water at the construction period. In the Hetao area the construction period in each year lasts only about 80 d. Therefore, using a concrete block often causes construction tension and worse qualitybecause of very limited time. Only smoothing the bedand laying are needed for the GCLs construction. As a result, construction period can be greatly shortened.

4. CONCLUSIONS

1. Hydraulic conductivity(HC) of the three tested GCLs used as new lining materials in canals increased from 2×10^{-12} - 6×10^{-9} to 1.1×10^{-6} cm s^{-1} - 1.6×10^{-8} cm s^{-1} in three years, tending to be steady state. It still meets the anti-seepage requirements.

2. GCLs used in irrigated areas have greater advantages comparing with the concrete block lining. GCLs materials have the advantages of frozen resistance, lower cost and facilitating construction. The most striking feature of GCLs is that the flexible property better adapts to frozen swelling in winter GCls should have great potential in canals lining materials in North China.

3. The cost of GCLs plus external protective layer such as cement slurry or cements mixed with earth for the grades up lateral canal could be decreased by 50% comparing with the concrete block. The larger the cross sections of canal the greater of cost saving with the application GCL.

4. The bentonite is from natural resource, which is ally friendly to environment.The further research should be undertaken on improving GCL performance to resist cation repalcement and develop more effective external protective materials.

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