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Study on fatigue properties of basic magnesium sulfate cement reinforced concrete beams based on response surface methodology

J. Zhang[1*], Y. Wen[2], L. Chen[3]

[1] *Vocational and Technical College of Inner Mongolia Agricultural University, China*
[2] *Educational Center of Tumoteyou Banner, Baotou City, China*
[3] *Chengdu Agricultural College, China*

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In order to study the fatigue properties of basic magnesium sulfate cement reinforced concrete beams, specimens of basic magnesium sulfate cement (BMSC) and ordinary Portland cement (PO·C) in strength grade of C40 and C50, respectively, were prepared. Response surface methodology was applied to this study. The results showed that under the fatigue load, the deflection value of the specimen decreases with the increase of the number of fatigue cycles. The fatigue cycle life of the BMSC specimens with higher strength grades is longer than that of the PO·C specimens, and the higher the strength grade, the more obvious the effect is. Under the fatigue load, the development of the mid-span deflection of the specimen showed an S-shaped trend, and the deflection in the BMSC specimen was smaller than that of the PO·C specimen. The spacing of the cracks in BMSC columns was smaller than that of PO·C columns because of the better bond performance between the reinforcing bars and the surrounding BMS concrete. But the crack widths of BMSC columns were close to the width of PO·C columns. It shows that the BMSC specimen has a high rigidity and good resistance to deformation.

Keywords: BMSC; reinforced concrete; fatigue property; Response surface methodology

INTRODUCTION

Basic magnesium sulfate cement (BMSC) is a new kind of sulfur magnesium oxychloride cement. The primary hydration product of BMS is the 5·1·7 phase [1-3]. Its chemical composition is $5Mg(OH)_2 \cdot MgSO_4 \cdot 7H_2O$. The main advantages of BMS are low cost, early strength, high tensile strength, and corrosion resistance [2]. The chemical, physical, and mechanical properties of BMSC are close to those of Portland cement [4].

Energy conservation and environmental protection are the topics that are fully advocated in the development of modern society and the progress of human technology. It is well known that the technology of "twice grinding and once burning" is widely used in the calcium cement, which consumes a lot of energy. Magnesium oxide, which is one of the main raw materials of BMSC, needs only magnesite to be calcined at about 900 °C. In contrast, the clinker of Portland cement needs to be calcined at high temperature of 1,450 °C. In the process of producing Portland cement, raw materials and cement have to go twice through grinding. The raw materials and cement are difficult to grind and 10% of the total energy consumed is electricity. In contrast, magnesium oxide is ground after the decomposition of magnesium carbonate, which is liable to be ground and only needs to be ground once [5-8]. BMSC production has no other energy consumption. In addition, Portland cement and its products are difficult to be recycled, while the hydration activity of BMS can be recovered at low temperature and then BMSC can be recycled. Above all, improvement of the performance of BMSC and expansion of its application in civil engineering not only can meet the requirements of energy conservation and environmental protection, but also coordinate for the sustainable economic development.

BMSC concrete is air-dried, magnesia-based concrete. Since the additives in BMSC can inhibit the hydration of MgO to weaken the crystallization stress and low solubility 5·1·7 phase, BMS concrete has better water resistance [5]. BMSC concrete has also advantages in corrosion resistance compared with Portland cement and sulfate aluminate cement [9-11]. It is therefore appropriate for high-performance, anti-corrosion concrete commonly used in salt-saturated, land environments [12-16].

In order to facilitate the large-scale application of basic magnesium sulfate cement concrete in structural engineering, a basic magnesium sulfate cement reinforced concrete beam member was prepared in this paper. Based on the static load and fatigue tests of basic magnesium sulfate cement reinforced concrete beams the fatigue properties of basic magnesium sulfate cement reinforced concrete beams were discussed by comparing with ordinary Portland cement reinforced concrete beams.

* To whom all correspondence should be sent:
E-mail: 245916447@qq.com

MATERIALS AND METHODS

In this experiment, the primary material was BMSC with a specific surface area of 2,500 cm^2/g, which was made of MgO, $MgSO_4 \cdot 7H_2O$, fly ash, and admixture. A kind of locally available crushed gravel with a maximum size of 25 mm and specific density of 2,680 kg/m^3 was used as the coarse aggregate. A locally available natural river sand with a fineness modulus of 2.44 and specific density of 2,700 kg/m^3 was used as the fine aggregate.

Preparation of the reinforcement concrete columns

Six BMSC columns and two PC concrete columns were tested to investigate the different behavior of the two kinds of columns. The length of the reinforcement concrete columns was 1,500 mm. The thickness of concrete cover was 25 mm.

RESULTS AND DISCUSSION

It can be seen from Fig. 1 that with the increase in the molar ratio, the flexural strength and compressive strength of the sheet first increase and then decrease. When the molar ratio is 6-8, the overall strength is the highest. When a-MgO/$MgSO_4$ is small, that is, when the content of a-MgO is low, the content of a-MgO hydration layer in the OH- and solid phase of the pore solution in the cement hydration process is small, resulting in strength. Phase 517 is slow to generate, resulting in lower early strength. When the a-MgO content is high, the remaining a-MgO after the formation of the 517 phase is hydrated to a lower strength $Mg(OH)_2$, that is, the 517 phase content per unit volume of the plate is lower, so the strength is also obviously reduced, therefore, it is recommended to choose a molar ratio of 6 to 8 when preparing the board.

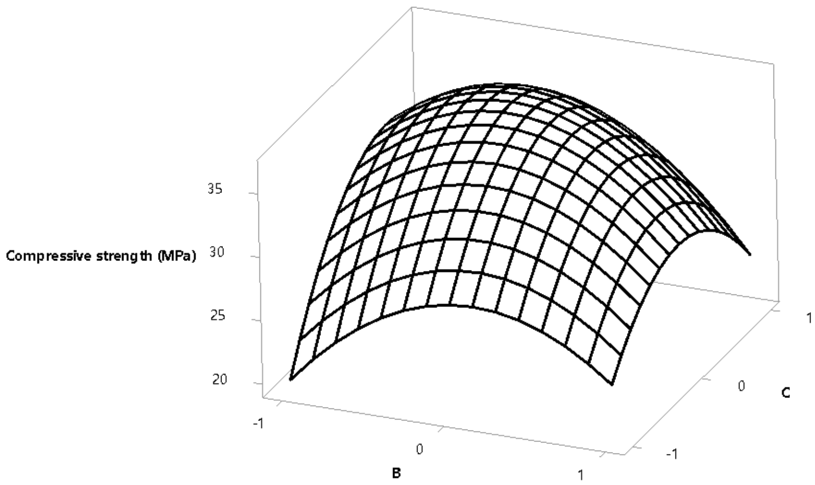


Figure 1. Surface plot of compressive strength (MPa) *vs* C, B

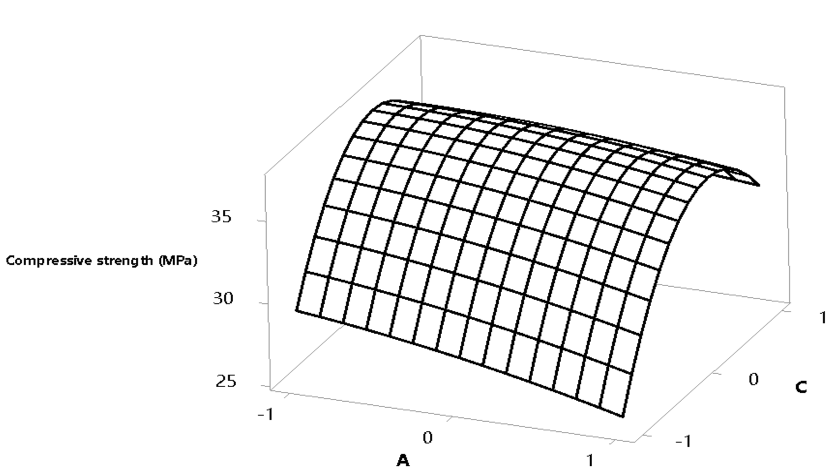


Figure 2. Surface plot of compressive strength (MPa) *vs* C, A

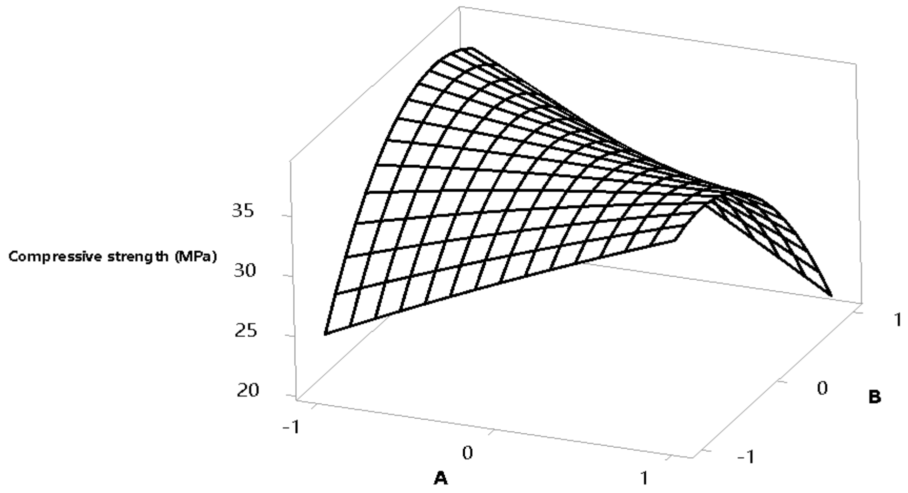


Figure 3. Surface plot of compressive strength (MPa) *vs* B, A

Figure 2 shows the effect of the amount of admixture on the strength of the composite sheet. It can be seen that the addition of the admixture has a great influence on the strength of the composite sheet. When no additives were added, the compressive strength was only 17.4 MPa, while when 0.4% of the admixture was added, the increase was 36.6 MPa, an increase of 110.3%.

In order to accelerate the production efficiency of the board, especially in winter production, sometimes manufacturers can adopt the method of early high temperature curing. Therefore, it is necessary to study the influence of temperature on the strength of the board and the mechanism of its influence. Figure 3 shows the effect of different early curing temperatures on the properties of the sheet. It can be seen that increasing the curing temperature can significantly increase its early strength. For example, after curing at 20°C for 1 d, after 50 h at 50°C and 80°C for 12 h, the compressive strength reached 17.6 MPa and 19. 8 MPa, compared with 24°C at the same age. 0 MPa increased by 90% and 145%, respectively. After 7 days of curing at 50°C, the compressive strength was only reduced when it was maintained at 20°C for 28 days 7%. The early curing temperature was 80°C, and the compressive strength decreased by 14.6%.

The curing process has a great influence on the performance of the composite sheet. The use of early high-temperature curing can accelerate the production efficiency of the sheet, increase the curing temperature, and increase its early strength. The late strength still has an increasing trend with the increase in age. Therefore, in the industrial production of composite sheets, the curing temperature is appropriately increased, and the production efficiency can be improved while the durability of the strength can be ensured. For Fig. 4, optimization of operating parameters is necessary to determine the optimum value of variables that yield the highest compressive strength. Optimization was done by a program based on the proposed quadratic model obtained for compressive strength. A desirable goal in the program was set for independent factors in the range with equal importance of 3 and for compressive strength at a maximum level with an importance factor of 5. Totally, 15 solutions were predicted by the software under the above-mentioned conditions. The optimum solution was selected based on economic considerations, availability and cost of reagents and energy. Based on these, curing temperature is 20°C, molar ratio is 7, additional dose is 0.6%.

Figure 5 shows the relationship between deflection and the number of fatigue cycles. It can be seen that under the fatigue load, the deflection value of the specimen decreases with the increase in the number of fatigue cycles. The fatigue cycle life of the BMSC specimen with high strength grade is longer than that of the PO·C specimen and the strength grade is higher. The high-strength BMSC specimens have a higher resistance to fatigue damage than the PO·C specimens.

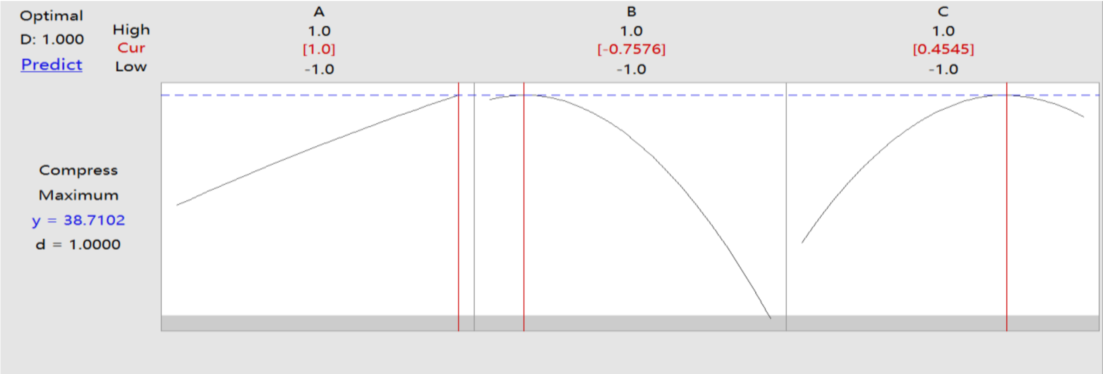


Figure 4. Multiple response prediction.

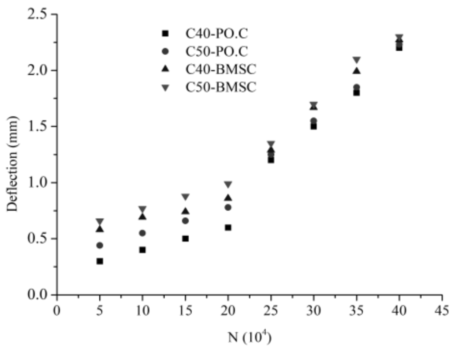
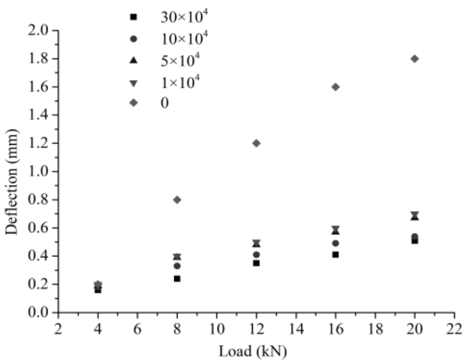
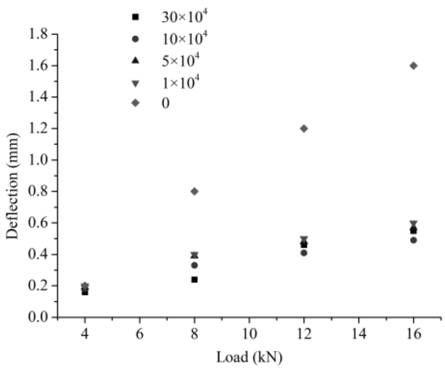


Figure 5. Relationship between deflection and fatigue cycles.



(a)



(b)

Figure 6. Deflection-load curves under fatigue load (a) BMSC specimen (b) PO·C specimen.

Figure 6 shows the cross-center deflection of the specimen *versus* the load at different fatigue cycles. It can be seen from the figure that the mid-span deflection of the specimen increases with the increase in the load. In the case of the same load, the mid-span deflection decreases with the increase in the number of fatigues. It can also be seen from the figure that the development of the mid-span deflection increment shows an S-shaped trend. At the initial stage of loading, and near fatigue failure, the deflection of the specimen during the mid-span will change greatly. Under the same conditions, the mid-span deflection of BMSC specimens is smaller than that of PO·C specimens. It shows that the BMSC specimen has high rigidity and good resistance to deformation.

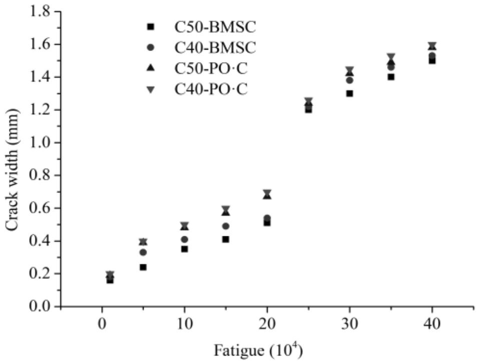


Figure 7. Relationship between fatigue and crack width.

The relationship between crack width and fatigue number of BMSC specimens is shown in Fig. 7. As the number of fatigues increases, the crack width of the test piece increases. Similar to the development of cracks in the static load test, new cracks are generated during the fatigue test, and the original cracks are continuously developed during the fatigue process. Under the same conditions, the crack width of the BMSC specimen is smaller than that of the PO·C specimen, and it can be seen that the BMSC specimen has high crack resistance.

CONCLUSIONS

Based on the results of this study, the following conclusions are drawn:

Under the fatigue load, the deflection value of the specimen decreases with the increase in the number of fatigue cycles. The fatigue cycle life of the BMSC specimens with higher strength grades is longer than that of the PO·C specimens, and the higher the strength grade, the more obvious the effect is. Under the fatigue load, the development of the mid-span deflection of the specimen showed an S-shaped trend, and the deflection in the BMSC specimen was smaller than that of the PO·C specimen. The spacing of the cracks in BMSC columns was smaller than that in PO·C columns because of the better bond performance between the reinforcing bars and the surrounding BMS concrete. But the crack widths of BMSC columns were close to the width of PO·C columns. It shows that the BMSC specimen has high rigidity and good resistance to deformation.

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