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Effect of Low Temperature Action on the Mechanical Properties of Modified Rubber Concrete

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Abstract. This paper investigates the mechanical properties of rubber concrete after low-temperature action (0°C, -20°C, -60°C and -100°C) compared with room temperature (20 °C), and provides a reference basis for the subsequent establishment of the strength modification model of rubber concrete under low-temperature action. The results show that the internal void structure of rubber concrete is improved and the compressive strength value increases under the effect of low temperature, and this strength increase effect is no longer obvious at lower temperature; the modified rubber particles have better ductility characteristics, and the tensile to compressive ratio of modified rubber concrete and unmodified rubber concrete will gradually decrease after lower than -60°C.

Keywords. Rubber concrete, mechanical properties, low-temperature action

1. Introduction

Concrete structures are the most widely used structural type in the world today. Long-term practice has shown that ordinary concrete has significant performance deficiencies, such as high early shrinkage, high brittleness and low strain capacity, which cannot be solved by simply adjusting the established material mixes. Modern research has made numerous improvements to concrete by adding various new materials to compensate for the deficiencies of rigid concrete. Some of these scholars have attempted to incorporate rubber aggregates into concrete to improve the use of concrete by bringing into play the common advantages of the two materials, while also conforming to the current national concept of green protection.

Feng et al. [1] study the degree of influence of rubber particle size and admixture on the mechanical properties of concrete, the study shows that rubber as an organic material, and inorganic cement stone bonding effect is much less strong than the bond between sand and cement stone, along with the increase in the admixture of rubber particles, its cubic compressive strength is roughly linear decline. In addition, the smaller the particle size of rubber particles incorporated, the larger the specific surface area occupied in the mixed aggregate, there will be more weak interfaces generated, which is a detrimental factor for bearing the load. Although studies have shown that the reduction of rubber particle size in blended concrete causes greater strength loss, most studies have found

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that rubber concrete with greater fineness has improved resistance to impact [2, 3], bending [4, 5], and durability [6, 7] compared to brittle base concrete.

In view of the many drawbacks of directly blended rubber concrete, many scholars have adopted a modified approach to rubber concrete. Onuaguluchi [8] and Zhang [9] all used cement material pre-coating to harden the rubber and the test results were better than the normal direct admixture type. The pre-treated rubber particles are enhanced in terms of elastic modulus, reducing the vulnerability of the rubber itself to superelasticity; on the other hand, the operation of coating the cement paste with rubber is relatively easy to implement, transforming the original rubber particles surface water repellency into contact inorganic water absorption, which is the main reason for improving the strength of concrete.

For special environments, such as some metallurgical and chemical enterprises high-temperature workshop and polar marine environment, the corresponding structural facilities need to experience extreme temperature environmental conditions, comprehensive research results show that: most of the current research on the performance of rubber concrete focused on room temperature and high temperature category, part of the experimental research only control simple factor variables and did not fully consider the impact of environmental temperature on mechanical properties, limiting its This limits the scope of its application in engineering practice. In addition, it is relatively rare to carry out mechanical properties tests of rubber concrete under low temperature. In order to verify the suitability of rubber concrete structures under low temperature conditions, the mechanical properties of modified rubber concrete before and after low temperature action are studied.

2. Specimen Preparation

According to the concrete proportion design specification (JGJ 55-2011) design basis C30 concrete, after preliminary calculations, the final ratio of ordinary concrete was determined as follows: cement (310.0 kg), sand (682.0 kg), stone (1137.0 kg), water (157.5 kg) and fly ash admixture of 54.6 kg, and water reducing agent dosage of 3.2 kg. The test used rubber particles equal volume to replace part of the fine aggregate sand, respectively configured coarse rubber particles (M class: 1-3 mm) concrete, fine rubber particles (N class: 40-60 mesh) concrete, the proportion of admixture are increased from 5% to 20%, concrete specific ratio is shown in Table 1.

Table 1. Mix ratio of rubber concrete.

Materials (kg/m^3)	**C**	**S**	**NCA**	**W**	**FA**	**WA**	**RP**	**Ratio**
NC-0	310.0	682.0	1137.0	157.5	54.6	3.2	0	0
RC-M-5%	310.0	647.9	1137.0	157.5	54.6	3.2	14.8	5%
RC-M-20%	310.0	545.6	1137.0	157.5	54.6	3.2	59.4	20%
RC-N-5%	310.0	647.9	1137.0	157.5	54.6	3.2	10.1	5%
RC-N-20%	310.0	545.6	1137.0	157.5	54.6	3.2	40.3	20%

Note: NC is natural concrete, RC is rubber concrete; x in RC-x-y indicates the range of particle size, y is the proportion of rubber admixture.)

Cube specimens of 100 mm × 100 mm × 100 mm were made for each of the above types of rubber concrete.

3. Experimental Results and Their Analysis

3.1. Compressive Strength and Index

Figure 1 shows the cubic compressive strength test curve of rubber concrete at low temperature. It can be seen that the benchmark rubber concrete NC-0 has strength advantages over various types of rubber concrete at low temperatures, and the strength of the benchmark concrete has a slight strength decreasing trend at 0℃ in the interval of experiencing temperature from 20℃ to -100℃, and the strength continues to increase at subsequent temperatures. As the temperature continues to decrease, the compressive strength of the base concrete increases very significantly.

The strength change trend of the three types of rubber concrete is similar to that of the benchmark concrete, indicating that the improvement effect of low temperature on rubber concrete is also considerable. However, overall, the strength improvement effect of rubber concrete at low temperature is slightly better than that of ordinary rubber concrete.

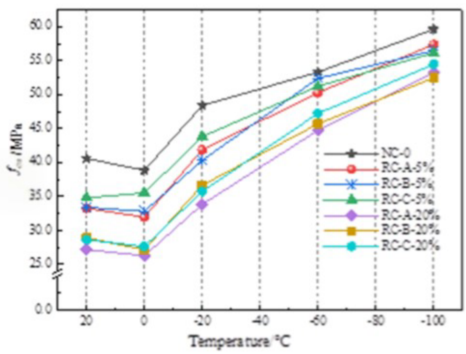

Figure 1. Compressive strength at low temperature.

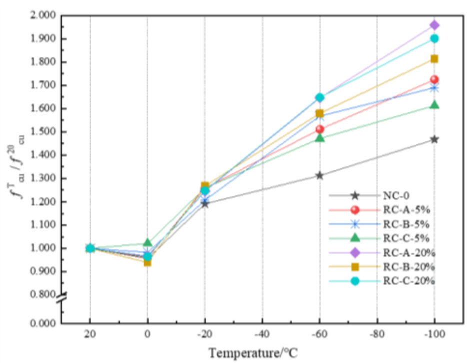

Figure 2. Relative compressive strength at low temperature.

Figure 2 shows the relative compressive strength f^{T}_{cu}/f^{20}_{cu} of various types of concrete at low temperature (compressive strength f^{T}_{cu} at low temperature vs. compressive strength f^{20}_{cu} at room temperature), which can clearly reflect the trend of cubic compressive strength of concrete subjected to different low temperature effects.

According to the data examination, it is found that the minimum value of relative compressive strength of concrete at low temperature is controversial. Wang [10], Xue [11] and Yang et al. [12] believe that there is a loss of concrete strength around 0°C, and the temperature interval around -25°C is the stage of concrete compressive strength enhancement, while Shi et al. [13] of Tsinghua University show through a large number of ultra-low temperature tests that the minimum compressive strength of concrete is reached at -20°C. Most scholars have concluded that the compressive strength of concrete at -40°C and lower temperatures has a significant increase. The high moisture content of concrete at -80°C is close to 2.0 times that of concrete at room temperature, indicating that moisture content is a key factor affecting the magnitude of strength increase, and as the temperature decreases under the conditions, the ice bodies condensed in the concrete macropores get further grown into the capillary voids with smaller size specifications, increasing the volume of ice bodies and providing strong support to the internal structure of concrete.

3.2. Splitting Tensile Strength and Index

Figure 3 shows the changes of splitting tensile strength of various types of concrete under the effect of low temperature. It is found that all types of concrete have the same loss of splitting tensile strength in the 0°C interval, and the difference in the magnitude of the loss is small, and there is a substantial increase in the splitting tensile strength in the cooling interval after the low temperature of -20. The three types of low-doped rubber concrete have the same trend of splitting tensile strength in each temperature interval, but the modified rubber concrete has a slightly stronger growth trend in splitting tensile strength. The reason for this is that the modified rubber particles have better roughness, which makes the interface more dense and reduces the internal porosity of the concrete. After the low temperature effect, the ice body inside the void fills the void and becomes harder as the temperature decreases, and the occlusal bonding ability between the sharp ice body, rough rubber particles and the cement matrix becomes stronger, thus increasing the splitting tensile strength of the specimen.

Figure 4 reflects the tensile to compressive ratio (tensile strength f^{T}_{ts} / f^{T}_{cu}) curves for the base concrete and the rubber concrete at low temperatures. When the concrete is in the same ratio, the higher the value of the tensile to compressive ratio, the better the ductility of the material. Compared to the base concrete, the rubber concrete has a relatively high tensile to compressive ratio. According to the graph, it can be observed that the tensile ratio fluctuates slightly from 0°C to -20°C when the temperature continues to decrease, but the overall decreasing trend is obvious and generally better than the base concrete. And the tensile to compressive ratio of all types of rubber concrete gradually decreases after the temperature is at -60°C, and the cubic compressive and splitting strength is improved.

The splitting tensile strength of the high-mix rubber concrete at low temperatures measured during the test was not included in the subsequent graphs because of the large dispersion, which affected the quantitative analysis of the follow-up. In general, the strength increase of high admixture rubber concrete is higher than that of low admixture rubber concrete.

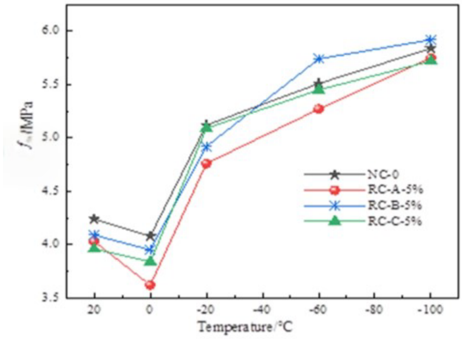

Figure 3. Splitting tensile strength at low temperature.

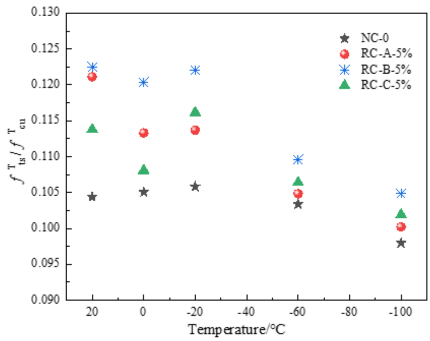

Figure 4. Tension-compression ratio at low temperature.

4. Conclusions

This chapter studies the mechanical properties of the benchmark concrete and three types of rubber concrete, RC-A, RC-B and RC-C, under low temperature action. The main conclusions obtained are as follows.

(1) In terms of compressive performance, the compressive strength of all kinds of concrete is partially lost at 0 ℃, and the increase of cube compressive strength is relatively obvious when the temperature continues to drop. The compressive strength of high content rubber concrete (whether modified or unmodified) is weaker than that of low content rubber concrete, which modified low-doped rubber concrete compressive strength value increases, strength growth is also obvious, but the fastest strength growth is still expressed as Base concrete. The relative compressive strength index shows that the internal void structure of rubber concrete is improved under the effect of low temperature, and this strength growth effect is no longer obvious at the lower temperature under the same admixture, which is initially analyzed as the internal skeleton has been filled with solid ice.

(2) In terms of tensile properties, all kinds of concrete have the loss of splitting tensile strength in the range of 0 ℃, and the difference of loss range is small, in the -20°C low temperature after the cooling interval of the splitting tensile strength has a substantial increase, but the modified rubber concrete in the splitting tensile growth trend

is slightly stronger. The tensile ratio index shows that the modified rubber particles have better ductility characteristics, and the tensile ratio of modified and unmodified rubber concrete gradually decreases after lower than -60°C.

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