Experimental Investigations on Self Compacting Gangue based Pavement Concrete

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Abstract: Gangue production has expanded more quickly in recent years due to the coal mining industry's rapid growth, although its utilisation has remained comparatively low. There is a significant environmental issue as a result of the vast amount of gangue that has accumulated. In order to increase the rate at which waste gangue is utilised and to address the secondary environmental issues brought on by gangue pollution, research was done in this study on an affordable and ecologically friendly self-compacting concrete made from gangue. The moisture content of gangue and limestone were compared in this study using aggregate industrial-analysis procedures, and it was discovered that gangue has a 39% greater moisture content than limestone. The study examined the fluidity, compressive strength, splitting strength, and abrasion resistance of self-compacting gangue using orthogonal experimental techniques. The optimal replacement rate of gangue for coarse aggregate is approximately 30%, the optimal replacement rate of fly ash for cement is approximately 30%, the optimal addition of polycarboxylate superplasticizer is approximately 0.5% of the mass of cementitious materials, and the optimal rate of shear steel fibres is approximately 1% of the concrete capacity, according to this study. In addition, the interfacial transition zone (ITZ) of the aggregate-cement slurry was examined, and it was discovered that the ITZ.

Keywords: self-compacting concrete; gangue; mixing ratio; interface transition zone (ITZ)

DOI: 10.48047/ecb/2023.12.11.38

1. Introduction

Management of solid waste has long been a major worldwide issue. In a study titled Global Waste Management Outlook, published on September 6, 2015, the United Nations Environment Programme (UNEP) and the International Solid Waste Association (ISWA) urged nations to act right away to increase resource recycling. According to China's "Guidance on the Comprehensive Utilisation of Bulk Solid Waste in the 14th Five-Year Plan," which was published on March 18, 2021, the rate of complete utilisation of bulk solid waste, including coal gangue and fly ash, should be 60% [1,2]. With over 10 trillion tonnes of reserves, coal is by far the largest utilised fossil fuel in the world. The solid refuse left over from coal mining is called gangue. Uncompleted data indicates that as of 2021, China's total gangue production had surpassed 6 billion tonnes, and there were 1500–1700 structured gangue mountains spread throughout an area larger than 133 square kilometres. A significant gangue buildup has had severely negative consequences on the environment since it contains combustible Fe2S material that is simple to burn and explode [3,4].

The utilisation of gangue is one of the main study issues among researchers from different nations in order to achieve global sustainable development. Numerous research on the utilisation of gangue have been done recently, including topics like gangue power production, gangue pavement, employing gangue as building materials or chemical raw materials, etc. The findings demonstrated that gangue concrete's compressive strength could satisfy the design specifications for C30 concrete and was appropriate for low- and medium-strength concrete. The fact that gangue is rich in silica, alumina, and other ingredients that speed up the hydration of cement to create AFT demonstrates that it may be utilised as an alkaline excitation material of cement, according to Moghadam et al.'s summary of the utilisation of gangue as an alkali-active material in [5]. In their study of the use value of gangue in geotechnical engineering, Ashfaq et al. [6,7] discovered that it may lower the amount of carbon dioxide (CO2) released during the collection and delivery of natural aggregates, which is good for the environment. After adding gangue and gravel to the concrete interface, Mei et al. [8] discovered that there are noticeable changes in the transition zone. The transition zone of the concrete contact gets narrower and denser as the gangue content rises. Using gangue as coarse and fine aggregates, Meng et al. [9] discovered that, within a particular range, the sand ratio was favourably connected with concrete density and negatively correlated with porosity. The coarse aggregate's particle size was the primary factor affecting compressive strength, and as the particle size grew, so did the compressive strength. According to Su et al. [10], gangue fracture is the primary cause of the compression and anti-splitting failure mode of gangue concrete. However, gangue absorbs water more quickly than natural gravel, so as gangue replacement rates rise, the water-cement ratio decreases, which is better for increasing the compressive strength of the concrete. According to Bai et al.'s research [11], the stress-strain curve of gangue concrete is comparable to regular concrete's in the rising stage. Although there is a quick decrease and the fitting result is distinct from the actual, the fitting effect is good.

Concrete that can be entirely filled with formwork by gravity alone, without the use of vibratory compaction, is known as self-compacting concrete (SCC). Its benefit over regular concrete is its high flow and filling capacity. Self-compacting concrete is frequently used for paving and filling intricate terrain constructions due to its high fluidity, high cohesiveness, high water retention, and strong durability [12,13]. According to energy spectroscopy, Choudhary et al. [14] discovered that the lower the Ca/Si ratio in the concrete mix, the higher the compressive strength. According to Han et al. [15], excessive superplasticizer and vibration will weaken the anti-segregation capabilities of SCC, with vibration having a more pronounced effect. According to Xie et al. [16], concrete slump expansion was lowered as well as slump flow with an increase in the coarse-to-fine-aggregate volume ratio. According to Zhu et al. [17], the workability of SCC is adversely associated with the volume ratio of coarse aggregate. The highest performance of concrete is achieved when the volume ratio of coarse aggregate is 33% and the grading is (5-10 mm: 10-16 mm: 16-20 mm = 30%: 30%: 40%). Fly ash was identified by Shi et al. [18] as one of the crucial SCC additions. Concrete fluidity and fly ash content are positively associated when fly ash makes up less than 40% of the total cementitious ingredients. According to Qiu et al. [19,20], the 30% fly-ash content altered the physical and chemical characteristics of the gangue aggregate interface, reducing the width of ITZ pores and cracks and having the ability to block large pores on the surface of the gangue, reduce the gangue's water absorption, fully hydrate the cement, and improve interfacial adhesion, all of which improved the mechanical properties of concrete. Large holes in the ITZ are caused by fly ash concentrations of 10% and 40%.

According to Shcherban et al. [21], who investigated how micro-silica affected the functionality of light fibre concrete, the concrete can have a more dense C-S-H microstructure and more favourable mechanical characteristics when it contains 10% cement. Because it has greater compressive, splitting, and flexural strengths than regular concrete, steel-fiber concrete is commonly employed. When the volume percentage of steel fibres is 1.0% and the aspect ratio is 25, SCC performs best, according to Rao, Ghasemi et al. [22,23]. From the loaded end to the free end, concrete interface damage develops as a result of the addition of steel fibres. When steel fibres are present in the stress-concentration zone and the maximum aggregate particle size is 12.5 mm, concrete's ability to absorb energy during fracture can be increased, which prevents concrete from becoming damaged as quickly. The slump expansion and segregation rate of self-compacting steel-fiber-reinforced concrete are inversely associated with the fibre coefficient, according to Ding, Wang et al. [24,25].

While many academics have studied self-compacting concrete, gangue concrete, and steel-fiber concrete extensively, very few of them have examined the effects of mixing components, and no equivalent proportioning method has been developed. This study effectively combines the benefits of gangue concrete and steel-fiber concrete with the high-flow filling capacity of self-compacting concrete to create a self-compacting gangue-based concrete. It is crucial for increasing the rate at which industrial waste gangue is utilised, lowering the environmental harm caused by gangue buildup, and realising its engineering worth. In order to clarify the differences between gangue and limestone in terms of water absorption rate and other factors, this study developed gangue and limestone industrial-analysis experiments. It designed a ratio experiment for gangue-based self-compacting concrete using orthogonal experiments and investigated its slump expansion, mechanical characteristics, and abrasion resistance. The transition zone (ITZ) between the gangue aggregate and slurry was also researched, and a connection was made between the ITZ, the mechanical characteristics of concrete, and gangue strength. Durability testing was not necessary because this study was appropriate for usage in typical concrete pavements and did not include hostile, high CO2 concentration, or water-rich settings.

2. Materials and Experiments

2.1. Materials

The standard PO. 42. 5 ordinary silicate cement and Grade I fly ash were used in the investigation. The maximum particle size of coarse aggregate shall be 16 mm, in accordance with JGJ/T283-2012 Self-compacting Concrete Application Technical Regulations. The average particle size of the coarse aggregate employed in this investigation ranged from 5 mm to 15 mm and contained some limestone.

2.2. Specimen Preparation

In addition to attempting to find the ideal mix ratio, this research focuses on how gangue, fly ash, polycarboxylate superplasticizer, and steel fibre additive affect slump expansion, 28 d mechanical characteristics, and abrasion resistance of concrete. The majority of academics [10] place the recommended fly-ash dosage between 10 and 40% of the cementitious material, the recommended polycarboxylate superplasticizer dosage between 0.5 and 1.5% of the cementitious material, and the recommended steel-fiber dosage less than 2% of the weight of concrete. The quantity of gangue may be regulated at any level, although it performs best when less than 40% of the weight of coarse aggregate is present. Based on the research of previous researchers, this study identified more precise optimal dose ranges for each element, particularly the ideal dosing rate. It set the fly-ash, gangue, polycarboxylate-superplasticizer, steel-fiber, and gangue admixture amounts in the cementitious material at 20%, 25%, and 30% of the total weight of concrete, respectively. It also set the amounts of gangue admixture in the total amount of coarse aggregate at 20%, 30%, and 40%. An orthogonal experimental design with four factors and three levels was created in accordance with the standards GB/T50080-2016 Standard for Test Method of Performance on Ordinary Fresh Concrete and 283-2012 Technical Regulations for the Application of Self-compacting Concrete. Put a mark by each factor's level as K1, K2, and K3, with each factor's average value levelled as K1, K2, and K3. The range and standard deviation results are denoted by the letters R and, respectively. A set of regular concretes devoid of gangue, fly ash, polycarboxylate superplasticizer, and steel fibre were created as the control group to simplify the comparative effect study. The experiment, which used concrete with a design fluidity class of SF2, 660 mm–750 mm, and a concrete design strength of C30, was carried out strictly in line with the protocol.

2.3. Testing Method

2.3.1. Industrial Analysis of Coarse Aggregate

The gangue and limestone were cleaned, dried, and then powdered using a grinding dish before being screened using a circular sieve with a 0.3 mm diameter. The powders were weighed and dried after screening; the temperature was adjusted to 80 C, and the powder was removed and weighed once per hour until the weight remained consistent. Using a WS-G818 automated industrial analyzer, the indications of moisture and volatile content in gangue and limestone were identified. The studies were conducted in accordance with the "Proximate Analysis of Coal" standard GB/T212-2008. With the temperature of the industrial analyzer set to 105°C, 815°C, and 900°C, the experiment was conducted by adding gangue powder and limestone powder to the crucible with a sample spoon. The decline in the weight of the powder in the crucible as the temperature increased from room temperature to 105 C was due to the moisture content in the gangue powder and limestone powder. The change in crucible weight was used to calculate the amount of ash present in the gangue and limestone as the temperature of the crucible steadily rose to 815 C. Determine the volatile component in gangue and limestone using the change in crucible weight as the temperature of the crucible gradually rises to 900 C.

2.3.2. Slump-Expansion Test

The first nine groups were divided into appropriate proportions and mixed using a mixer. No slump-expansion experiment was carried out on the control group since there was no slump-expansion phenomena to measure in that group. According to GB/T50080-2016 Standard for Test Method of Performance on Ordinary Fresh Concrete, the experiment was conducted.

2.3.3. Mechanical-Property Experiment

Concrete-compression tests and concrete-splitting tests were performed on the concrete specimens after a 28-day curing period. The trials were conducted using the pressure-testing device SHIMADZU AGX-250. For each series of studies, three pieces of concrete from the same batch were utilised, and the strength was calculated from their average value to reduce experimental error. The "Standard for Test Method of Mechanical Properties on Ordinary Concrete" in GB/T 50081-2002 was rigorously adhered to.

2.3.4. Abrasion-Resistance Test

The concrete test block was secured using clamps, and the wear position was indicated by drawing a line along the centre of the concrete surface. For the concrete-abrasion test, a 4 mm-thick grinding wheel was employed and the angle grinder handle was secured in place. The angle grinder was put in the position it would be worn during the abrasion test, and the test was conducted using only its own weight without the use of any external force. For each round of testing, a single concrete specimen measuring 100 mm by 100 mm by 100 mm was employed. Abrasion-resistance tests were performed on each specimen's six faces to establish the validity of the experiment. The length (L) and depth (H) of the abrasion marks were measured, and their average values were used as the test findings, respectively. The concrete wear volume was approximated using L H 4 mm (wheel thickness). Since the experiment called for the use of the same grinding wheel, the thickness of the wheel could be disregarded, and L H was utilised to determine an approximation of the degree of concrete wear damage. The abrasion resistance of the concrete decreases with increasing value.

2.3.5. Experiment of ITZ Structure Observation

This study innovatively introduced the slurry-encapsulated-aggregate experiment, which made microscopic experiments like SEM and EDS more convenient to be carried out and could better combine with macroscopic mechanical properties to improve the reliability of the results. This was done in order to better characterise the ITZ (interfacial transition zone) between aggregate and cement mortar and to ensure an effective combination of them.

The surfaces of relatively flat pieces of gangue and limestone were cleaned with water to eliminate impurities, and then one side was smoothed out before drying for 30 minutes at a predetermined temperature of 100 °C. The material was removed once drying was complete and chilled in a room setting to room temperature. The smoothed surfaces of the gangue and limestone were plastered, and they were kept in a maintenance box for seven days at a humidity level of 95% and a temperature of 20°C. They were then broken up to gather aggregates with 10 mm edge lengths/diameters and 2 to 3 mm thicknesses. For X-ray energy-dispersive spectrometer (EDS) and scanning electron microscope (SEM) measurement, the aggregate-slurry surface thickness was kept to within 0.1 mm.

3. Results and Discussion

Summarised are the findings from the aggregates' industrial analysis as well as the experimental findings on slump expansion, compressive strength, splitting resistance, and abrasion resistance. For each factor, range analysis and standard-deviation analysis were performed.

3.1. Aggregate Industry Analysis

The gangue and regular limestone differ primarily in their contents of volatile components and that gangue has a less stable structural makeup than limestone. The gangue's structure significantly alters at 900 °C, going from the initial crystalline phase to amorphous SiO2, Al2O3, and metakaolinite. Nevertheless, the primary component of limestone, CaCO3, is difficult to break down at 900°C and often requires to reach temperatures of 1000–1300°C before it can break down into quicklime (CaO) and release CO2. The bound water in gangue was 39% greater than in limestone, as can also be shown.

3.2. Slump Flow

The fly ash and polycarboxylate superplasticizer contents were the key factors impacting the concrete expansion in the concrete slump-expansion test, and the planned experimental groups fulfilled the design expansion criteria. The slump expansion of concrete was favourably associated with fly ash concentration within a particular range. The primary causes of this are (1) fly ash's predominantly spherical morphology, which when added to concrete reduces friction between cement particles or between cement particles and aggregates, allowing the concrete to flow more easily; and (2) the volume of fly ash in the slurry increases while the volume of cement in the slurry decreases. By adding the right amount of fly ash to the cement and water mixture, the viscosity of the slurry is decreased and the flow capacity is increased [18]. The association between polycarboxylate-superplasticizer dosage and concrete slump expansion also shown a favourable growing tendency within a certain range, The polycarboxylate superplasticizer can be used to make cement particles charge similarly. The mutual repulsion of homogenous charges theory states that when the repulsive force between cement particles grows, free water will be released from the wrapped cement, increasing the concrete's capacity to flow.

Steel fibre and gangue had a negligibly little impact on the slump expansion of concrete. The decline expansion had no evident shift trend because to the rise in gangue content. There was no discernible effect on the slump expansion of concrete when the mass of steel fibre made up less than or equal to 1% of the volume weight of concrete. The long strip of steel fibre had a certain obstructive impact on the slump expansion of concrete when its mass was larger than 1% of the volume weight of the concrete, and the curve displayed a downward trend. The impeding effect gets more pronounced as the number of steel fibres rises, and the slope of the curve falls even further.

3.3. Compressive Strength

The compressive strength of concrete decreased in comparison to the control group under the synergistic action of fly ash, gangue, polycarboxylate superplasticizer, and steel fibre; however, this decrease does not account for the optimised proportioning scheme and only reflects the influence of various factors on the compressive strength of concrete. The total strength of concrete fell because gangue's strength was lower than limestone's.

The compressive strength of concrete increased in a certain range (20–30%) with an increase in fly ash dose. One explanation for this might be that (1) as fly ash is added, cement is used less, the exothermic cement-hydration reaction is less severe, the temperature difference between the interior and exterior of the concrete is smaller, resulting in fewer temperature cracks, and internal stress in the concrete is smaller. (2) Fly ash's spherical shape improves the concrete's compactness by filling in the gaps between the cement and aggregate and reducing friction. (3) Fly ash stimulates the "volcanic ash effect". It combines with the cement-hydration products Ca(OH)2 to create more structurally stable hydrated calcium silicate and hydrated calcium aluminate crystals, which increases compressive strength.

The compressive strength increased and then declined with the steady rise in gangue within a range of (20-40%). Concrete's compressive strength increased when the gangue replacement rate was raised from 20% to 30%. This rise may have been caused by factors including a decrease in pores and bubbles in the interface transition zone (ITZ), which boosted the zone's strength.

In general, the CA and CM zones of concrete are the strongest, while the ITZ zone is the weakest because it has more dangerous pores and air bubbles than the CA and CM zones. Cracks propagate quite readily from the ITZ and have the most difficulty going through the aggregate when the concrete is compressed. As a result, there is a greater likelihood that the original fracture will expand down the ITZ until it reaches the CM. The number of cracks will gradually get longer and more numerous as the pressure increases, linking to form a spatial network that will eventually cause the concrete to fracture and crumble. Related research has revealed that ITZ (gangue) is denser and thinner than other varieties of ITZ (aggregate), which results in fewer holes, fractures, and bubbles. This gives ITZ (gangue) a greater strength than ITZ (limestone) [8]. Because CA (gangue) strength is lower than CA (limestone), when concrete is exposed to compressive stresses, the gangue's internal structure is firstly destroyed, increasing the likelihood that cracks will be generated from internal gangue. Then, the cracks spread to the ITZ, and then to the CM, so crack expansion may occur in a shorter path, decreasing the energy absorption of the concrete to reach breaking conditions as well as the strength.

ITZ-observation experiments for gangue and limestone were created in order to further support this result, and the experimental approach has already been covered. Under the circumstance that fly ash and polycarboxylic acid high-efficiency water-reducing agent work together, Group 3 and Group 6 may reflect the interfacial properties of the slurry material and coarse aggregate; for this reason, they are chosen as the study's representative groups. In contrast to ITZ (limestone), which was found to have a majority of fibrous, flocculent C-S-H gels and a limited number of Ca(OH)2 crystals with AFT crystals, ITZ (gangue) generated an abundance of needle and rod AFT crystals. Related research has demonstrated that concrete develops its initial strength more favourably when AFT and AFM crystals are present, resulting in higher ITZ (gangue) strength than ITZ (limestone) strength. C-S-H, one of cement's primary hydration products, helps to increase ITZ strength.

Group 3 of the gangue group produced more rod-shaped AFT and AFM crystals than Group 6 of the limestone group because Group 3 of the hydration reaction of cement produced the necessary temperature conditions for the formation of AFT and AFM crystals. Therefore, the development of concrete strength was greater when the aggregate particle size was between 5 and 15 mm and gangue was present in an amount of around 30%. Due to gangue's lower strength compared to that of limestone, when the gangue admixture rate was more than 30%, the skeletal strength reduced more noticeably, lowering the concrete's compressive strength. To further stimulate gangue surface activity, it may be possible to use a variety of research techniques, such as raising gangue temperature or expanding its specific surface area, strengthening the transition zone at the gangue-slurry interface, and then enhancing concrete's capacity to accommodate gangue.

When the dose of the polycarboxylate superplasticizer was increased under certain water-to-cement ratio circumstances, the compressive strength of concrete exhibited a tendency to decline. These might be the causes: (1) Under the circumstances of a specific water-cement ratio, the increase in the amount of polycarboxylate superplasticizer is equivalent to an increase in the water-cement ratio of the concrete. The cement mortar's liquidity increases and its bonding capacity decreases, as well as its bonding capacity with the aggregates and fibres. (2) When used with cement mortar, polycarboxylate superplasticizer increases the workability of concrete but also introduces a small quantity of air bubbles into the concrete as a result of its reaction with water. When the proper amount of polycarboxylate superplasticizer is added, the water-reducingagent particles cause the cement particles to have the same electric charge, which in turn causes the cement particles to disperse due to electrostatic repulsion, a process known as flocculation. If the cement does not add any water-reducing agent, CaO, Al_2O_3, and other elements will have hydration reactions, attracting water molecules in the vicinity of cement particles, which will flocculate and bond together. When too much polycarboxylate superplasticizer is added to concrete, the amount of air bubbles also increases, decreasing the concrete's compactness.

As a result, the best rate for this concrete proportion is about 0.5% of the total amount of polycarboxylate superplasticizer. The compressive strength of concrete displayed a tendency of early rising and subsequent declining with the increase in the dosage of steel fibres in a specific range (0.5-1.5%), as shown in Figure 10d. This could be because steel fibres absorb part of the pressure applied to concrete while it is under pressure. When the concrete achieves its damaged state, the fibres need to be deformed by an extra partial force. When the percentage of steel fibres reaches about 1.5%, the compatibility of steel fibres and coarse aggregates deteriorates, the distribution of steel fibres tends to be uneven when mixing, and a loose slurry interface structure tends to be produced between the grooves of the wavy steel fibres, with an increase in harmful pore bubble. The compressive strength of concrete is reduced in lightweight concrete when the steel-fiber component is 1%. As a result, the kind of concrete has a big impact on the ideal steel fibre mixing ratio.

3.4. Splitting Strength

Fly ash mixing rates of 30%, gangue mixing rates of 30% and 40%, polycarboxylate superplasticizer mixing rates of 0.5% and 1.0%, and steel fibre mixing rates of 1% and 1.5% were all greater than the control group's splitting resistance. We can observe that steel fibre had a greater impact on anti-splitting performance than it did on compressive strength, and it had better crack resistance, which caused certain experimental groups' splitting resistance to be higher than that of the control group.

The splitting strength remained essentially same while the fly-ash admixture was increased from 20% to 25% and the polycarboxylate-superplasticizer admixture was increased from 0.5% to 1%. When the quantity of fly ash was increased to 30%, the concrete's splitting strength improved; however, when the amount of polycarboxylate superplasticizer was increased from 1% to 1.5%, the concrete's splitting strength fell. The cause of this phenomena is the same as the study of compressive strength in the preceding section: fly ash primarily makes the concrete dense and increases the compatibility of the slurry. A particular water-to-cement ratio must be met for the polycarboxylate superplasticizer to be useful to the development of concrete compatibility; otherwise, it will create detrimental pores and reduce the strength of cement mortar. The splitting strength increased initially and gradually declined as the amount of gangue and steel fibres in the combination increased, as illustrated in Figures 18b,d. Figure 8c's findings show that gangue continues to be the most important of the four variables, and that the splitting-strength curve resembles the compressive-strength curve. For the same reasons that were examined in compressive strength, the 30% gangue dosage contributed the most to the splitting resistance, which may be explained in terms of the crack expansion route and energy consumption. At a steel-fiber admixture of 1% as opposed to 0.5%, the concrete's splitting resistance rose by around 19%, but the compressive strength only by about 3%. Comparatively, it was discovered that the enhancement of concrete's splitting resistance by steel fibres was nearly six times more than the enhancement of compressive strength. Steel fibres were mostly used in the concrete-splitting trials to transmit tensile and shear loads, and those in the shear area in particular had a clearly favourable incremental effect on the concrete's resistance to splitting.

3.5. Experimental Results of Abrasion Resistance

Only when the ratio of gangue reaches 20%, under the synergistic effect of the four components, is the wear amount somewhat less than that of the control group. Steel fibre and gangue are the primary determinants of concrete's abrasion resistance, and gangue has the biggest detrimental effect, causing concrete's overall abrasion resistance to be lower than that of the control group. With the addition of more fly ash, the small pores in the concrete are gradually filled and the overall structural compactness is improved, both of which increase the concrete's abrasion resistance. The concrete's resistance to abrasion reduced as gangue content increased; abrasion rises more quickly in the 30–40% admixture than in the 20–30% admixture, therefore this outcome is predicted; The gangue's abrasion resistance is lower than that of regular limestone since its own strength is comparatively low. The wea, thinning, and fractures of the gangue are inevitable when dded to concrete. The drop in the concrete's abrasion resistance, even at 30% admixture, is yet within acceptable bounds. When the amount of polycarboxylate superplasticizer is increased, the abrasion resistance of concrete decreases due to a decrease in cement-mortar strength and a weakening of the bonding force, which makes the cement-mortar layer of concrete easier to peel off under specific water-cement ratio conditions.

Concrete's resistance to abrasion tends to rise as the amount of steel fibres added increases, The use of steel fibres is advantageous in increasing the abrasion resistance of concrete because they have a greater abrasion resistance than brittle aggregates and cement mortars. Following the previous examination, Group 6's experimental proportioning scheme's concrete shown strong resistance to slump expansion as well as good mechanical and abrasion qualities. As a result, the study's findings suggest that the ideal ratio of gangue to fine aggregate should be around 30%, that the ideal ratio of fly ash to cement should be around 30%, that the ideal ratio of polycarboxylate superplasticizer to cement should be about 0.5%, and that the ideal ratio of steel fibre to cement should be about 1%.

4. Field-Application Effect

This investigation was executed in a field experiment in Lane 5315 of Shanxi Jinneng Holding Group Zhaozhuang Coal Co. after determining the ideal amount of self-compacting gangue concrete. The bottom had a thickness of 200 mm, a length of 50 m, and a width of 5600 mm. Following the installation of the bottom, irrigation maintenance was carried out prior to the collection of samples (200 mm 200 mm 200 mm) at 7 and 28 days, respectively, for compressive and splitting strength testing. Concrete had compressive values of 21.78 MPa and 32.25 MPa at 7 days and 28 days, respectively. The 28d compressive strength of the concrete was lower than that calculated using real ambient temperature (about 10 C) and curing conditions.

5. Conclusions

In this study, the optimal ratio of self-compacted gangue concrete was determined to be 30% coarse aggregate, 30% fly ash, 0.5% polycarboxylate superplasticizer, and 1% steel fibre. The relationship between the mechanical properties of concrete's ITZ microscopic components and its macroscopic structural components was also established.

(1) Fly ash and polycarboxylate superplasticizer had a greater impact on the slump expansion of SCC in the percentage range examined in this work than did steel fibre and gangue. Fly ash and polycarboxylate superplasticizer additive rate showed a positive correlation with concrete slump expansion. The slump expansion of concrete showed a clear decreasing trend as steel-fiber dosage rose from 1% to 1.5%, but gangue had essentially little impact on the slump expansion of concrete.

(2) The influence of gangue and steel fibre on the compressive and splitting strength of self-compacting gangue concrete was greater in the percentage range examined in this research than that of fly ash and polycarboxylate superplasticizer. Both the compressive and splitting strength have increased with the addition of gangue and steel fibres. In terms of mixing rates, 30% and 1% were ideal. The compressive strength and splitting strength of concrete both rose with the addition of more fly ash, and the ideal mixing rate was roughly 30%, respectively. The compressive strength and splitting strength of concrete both decreased with an increase in polycarboxylate-superplasticizer dosage, and the ideal mixing rate was around 0.5%, respectively.

(3) The impact of gangue and steel fibre on the abrasion resistance of self-compacting gangue concrete was greater in the percentage range examined in this article than that of fly ash and polycarboxylate superplasticizer. Concrete's ability to withstand abrasion was favourably connected with steel fibre and fly ash content and negatively correlated with gangue and polycarboxylate superplasticizer content. When the gangue concentration was between 30 and 40%, it dramatically dropped, but even at that level, the concrete still exhibited good wear resistance.

(4) It was discovered by SEM, EDS, XRD, and other investigations that the ITZ (gangue) produced more AFT crystals whereas the ITZ (limestone) produced less AFT. Due to the gangue's predominant composition of quartz (41%), illite (30%), and kaolinite (17%), there is a high concentration of Al, which promotes the growth of AFT and AFM crystals in ITZ, which is better for the long- and short-term development of concrete strength.

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