

Early Strength in Bitumen Using Chemical Admixture

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Abstract: The construction and maintenance of road infrastructure are critical components of urban development. Bitumen, a crucial binder in asphalt mixtures, plays a pivotal role in ensuring the durability and performance of road surfaces. Achieving early strength in bitumen is of paramount importance to expedite construction timelines and enhance the overall efficiency of road projects. This research explores the utilization of chemical admixtures as a viable strategy to accelerate the early strength development in bitumen. The study investigates various chemical admixtures and their impact on the rheological properties of bitumen. Through a comprehensive literature review, the research establishes a foundation for understanding the conventional methods of bitumen modification and the inherent challenges associated with achieving early strength. The focus then shifts to the exploration of chemical admixtures, encompassing a wide range of additives such as polymers, rejuvenators, and antistripping agents. Polymeric additives emerge as a key category of chemical admixtures, with their ability to significantly enhance the mechanical properties of bitumen. The research delves into the molecular interactions between polymers and bitumen to improve early strength. The study elucidates the chemical admixtures processes involved in rejuvenation and their influence on the viscosity and elasticity of bitumen. The study investigates their role in enhancing the adhesion between bitumen and aggregates, consequently preventing moisture-induced damage. By analyzing the surface energy interactions at the bitumen-aggregate interface, the research provides a comprehensive understanding of the mechanisms through which anti-stripping agents contribute to early strength development.

Keywords: Bitumen, Chemical Admixtures, Early Strength Development, Asphalt Pavement, Polymer Modified Bitumen, Rejuvenators, Anti-Stripping Agents.

INTRODUCTION

Bitumen is a viscous, black, and sticky substance derived from crude oil and plays a crucial role in road construction and transportation infrastructure. It is widely used as a binding material in flexible pavements due to its excellent adhesive, waterproofing, and durability properties. More than 85% of the world's bitumen production is utilized in road construction applications, making it one of the most important materials in pavement engineering. The performance and service life of flexible pavements largely depend on the quality and engineering characteristics of the bitumen used in the mixture. Early strength development in bitumen is an important requirement in modern pavement construction because it allows roads to be opened to traffic in a shorter period of time, reduces construction delays, and improves project efficiency. Conventional bituminous pavements often experience

problems such as rutting, cracking, moisture damage, and low early strength due to repeated traffic loading and adverse environmental conditions. These problems reduce pavement durability, increase maintenance costs, and shorten pavement service life. Therefore, there is a need to improve the performance characteristics of bituminous mixtures through suitable modification techniques. Bitumen contributes significantly to pavement strength through its ability to form a strong adhesive bond with aggregates. This bond is essential for resisting traffic-induced stresses and environmental effects while maintaining the structural integrity of the pavement. The adhesive properties of bitumen bind together all components of the mix without causing undesirable changes in aggregate properties. The strength and durability of pavement depend on several factors, including aggregate type, gradation, bitumen content, and the quality of bonding between aggregates and binder. Therefore, improving the bonding

characteristics of bitumen can enhance the overall performance of flexible pavements. Chemical admixtures have emerged as an effective method for improving the engineering properties of bitumen. These admixtures modify the physical and chemical behavior of bituminous mixtures and enhance pavement performance. Various chemical additives such as polymers, rejuvenators, anti-stripping agents, and mineral fillers have been used to improve strength, stability, durability, and moisture resistance. Among these additives, Calcium Carbonate (CaCO_3) has attracted considerable attention because of its ability to improve density, stiffness, stability, and early strength development in bituminous mixtures.

LITERATURE REVIEW

Road infrastructure plays a vital role in economic growth and transportation development. The performance and durability of flexible pavements are largely dependent on the engineering properties of bituminous materials used in their construction. Conventional bituminous pavements are subjected to repeated traffic loading, temperature variations, moisture infiltration, and environmental degradation, which often result in rutting, cracking, stripping, and premature failure. To overcome these limitations, researchers have explored various modification techniques using chemical admixtures, polymers, fillers, and nanomaterials to improve the strength and durability of bituminous mixtures.

Recent studies have shown that Calcium Carbonate (CaCO_3) is one of the most effective additives for improving the performance characteristics of asphalt mixtures. Ali (2018) investigated the effect of nano Calcium Carbonate on asphalt mixtures and reported significant improvements in resilient modulus, indirect tensile strength, moisture resistance, and dynamic modulus. The study revealed that the addition of Calcium Carbonate nanoparticles increased the resilient modulus by approximately 138% and improved indirect tensile strength by 48.18% compared to conventional asphalt mixtures. The research further concluded that asphalt modified with 6% Calcium Carbonate exhibited superior resistance to rutting and moisture damage, making it suitable for highway construction in hot and humid regions.

The modification of bitumen using Calcium Carbonate-based composites has also been widely studied. Erkus (2023) evaluated the physical and rheological properties of Calcium Carbonate-Polypropylene Composite

modified bitumen and compared its performance with Styrene-Butadiene-Styrene (SBS) modified binders. The results indicated that the incorporation of Calcium Carbonate composites increased softening point, viscosity, and rutting resistance while reducing penetration values. The study demonstrated that a 21% Calcium Carbonate-Polypropylene Composite modification produced performance characteristics comparable to those of SBS-modified bitumen and could serve as a cost-effective alternative for pavement applications.

Moisture susceptibility remains one of the major causes of pavement deterioration. Mehdinazar et al. (2025) investigated the influence of nano Calcium Carbonate on the low-temperature performance of asphalt mixtures exposed to acidic, alkaline, and neutral moisture conditions. The study reported that environmental exposure reduced bitumen-aggregate adhesion and increased the likelihood of thermal cracking. However, the addition of nano Calcium Carbonate significantly improved adhesion characteristics, increased fracture energy, and enhanced resistance to moisture-induced damage. The findings confirmed that nano Calcium Carbonate effectively improves the durability and long-term performance of asphalt pavements under adverse environmental conditions.

The influence of Calcium Carbonate whiskers on pavement performance has also been examined by several researchers. Xu and Xu (2022) compared the effectiveness of Calcium Carbonate whiskers and Calcium Sulfate whiskers in asphalt mixtures. The results showed that Calcium Carbonate whiskers improved high-temperature stability and water resistance within a specific dosage range. Although excessive addition reduced low-temperature performance, the study confirmed that Calcium Carbonate can significantly enhance pavement stability and moisture resistance when used in optimum proportions.

METHODOLOGY

The project aims to investigate the effect of chemical admixtures on the early strength of bitumen mixtures. Bitumen is a complex mixture of hydrocarbons used in road construction, and its strength development is crucial for ensuring the durability and longevity of pavements. Chemical admixtures can potentially enhance the early strength of bitumen, allowing for faster construction and reduced maintenance costs.

Aggregates

The stone aggregates are used in the construction of various pavement layers. Most of the aggregates are prepared by crushing of natural rock. The aggregates are specified based on their grain size, shape, texture and gradation. The crushed aggregates of different sizes are separated by sieving through square sieves of successively decreasing sizes. The required aggregate sizes are chosen to fulfil the desired gradation. The grading, tests, and specifications of stone aggregates for the different road making purposes have been specified by various agencies like IRC, BIS, ASTM and BSI. We have collected aggregates from construction site ongoing on our campus. We have collected a total of 50 kg of aggregates for our work. We have also collected around 5 kg of additional filler material. After collection we have sieved these aggregates from 12.5 mm IS sieve, 10 mm IS sieve, 4.75 mm IS sieve and 2.36 mm IS sieve.



Figure 2.1 Aggregate

Bitumen

A substance produced by the distillation of crude oil that is known for its waterproofing and adhesive properties. Bitumen production through distillation removes lighter crude oil components viz gasoline and diesel, leaving the heavier bitumen behind. Bitumen is a beneficial material that is used in various industries. More than 85% of the world's bitumen production is used for road construction, 10% is used in other constructions and 5% is used in a variety of other industries, including insulation. Bitumen is a viscous substance that exists in a liquid to a semi-solid phase. It has a blackish-brown colour. It is generally composed of asphaltic resin and other petroleum compounds. Different compositions of bitumen result in different properties. Bitumen is a complex organic material and occurs either naturally or may be obtained artificially during the distillation of petroleum. Bituminous materials are very commonly

used in highway construction because of their binding and waterproofing properties. Paving grade bitumen which is obtained from the distillation process of petroleum crude is extensively used in the construction of flexible pavement layers particularly the surface and binder courses.



Figure 2.2 Bitumen

Fly Ash

The use of fly ash as a lightweight aggregate (LWA) offers a valuable opportunity to recycle one of the largest waste streams. In addition, fly ash can offer many benefits, both economically and environmentally when utilized as a LWA. Depending upon the source and composition of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and calcium oxide (CaO), the main mineral compounds in coal bearing rock strata. SiO_2 , Al_2O_3 , Fe_2O_3 and occasionally CaO are the main chemical components present in fly ashes.



Figure 2.3 Fly Ash

Calcium Base Compound

Chemical admixtures are special materials added to bitumen in small quantities to improve the engineering properties and performance of flexible pavements. In conventional bituminous mixes, pavements may require more time to gain strength after construction. Due to heavy traffic and fast construction requirements, roads need to achieve sufficient strength at an early stage. Chemical admixtures help in increasing early strength, improving stability, reducing moisture damage, and enhancing durability of pavements.

These admixtures modify the physical and chemical behavior of bitumen and improve the bonding between bitumen and aggregates. As a result, the pavement becomes stronger, more durable, and resistant to rutting, cracking, and deformation.

Why Chemical Admixtures are Used in Bitumen

In road construction, bitumen acts as a binding material that holds aggregates together. However, ordinary bitumen may face problems such as low early strength, moisture damage, rutting under heavy traffic, cracking due to temperature changes, and weak bonding between aggregates and bitumen. Chemical admixtures are added to overcome these problems and improve pavement performance.

Calcium Carbonate (CaCO₃)

Calcium Carbonate is one of the most commonly used mineral fillers in bituminous pavement. It is a white powder material obtained from limestone and is added to bitumen to improve density and strength. It acts as a filler material and occupies air voids within the mix, making the pavement denser and stronger.

Functions of Calcium Carbonate in Bituminous Mix

Calcium Carbonate fills small air spaces between aggregates and creates a dense mix structure. It improves adhesion between bitumen and aggregates, resulting in stronger pavement structure. It increases stiffness of bituminous mix and helps pavement resist deformation. The stability value of pavement increases, improving load carrying capacity. Pavement gains strength quickly after construction and can withstand traffic earlier.

Tests Conducted on Bitumen

Penetration Test

Objective: To determine the consistency of bituminous material.

IS Standard Used: IS 1203–1978

Principle: Penetration value is a measurement of hardness or consistency of bituminous material. It is the vertical distance traversed or penetrated by the point of a standard needle into the bituminous material under specific conditions of load, time and temperature.

Table 3.1 Penetration Test Results

Penetration Dial Results	Test
Initial	0
Final	70

Observation Sheet

Parameter	Value
Pouring Temperature	30°C
Period of Cooling in Atmosphere	24 hr
Period of Cooling in Water Bath	30 min
Room Temperature	27°C
Duration of Releasing Needle	5 sec
Test Temperature	28°C

Conclusion: According to IRC, bitumen grade 60/70 and 80/100 is suitable for bitumen macadam and penetration macadam. Hence this sample of bitumen is suitable for road construction.

Ductility Test

Objective: To determine the ductility value of the given bitumen sample.

IS Standard Used: IS 1203–1978

Test Result = 40 cm

Table 3.2 Ductility Test Results

Readings	Test
Initial	1.5
Final	40
Ductility in cm	40 cm

Conclusion: As per standard minimum activity value is 40 mm, so the given bitumen sample can be used for road construction.

Tests Conducted on Aggregates

Aggregate Crushing Value Test

Table 3.3 Aggregate Crushing Value Test Results

Sr. No.	Details	Readings
1	Weight of Aggregate Sample (W_1)	7.61 gm
2	Weight Passing 2.36 mm Sieve (W_2)	1.3 gm
3	Aggregate Crushing Value ($W_2/W_1 \times 100$)	17.7%

Aggregate Crushing Value Result = 17.7%

3.3.2 Aggregate Impact Value Test

Table 3.4 Aggregate Impact Value Test Results

Sr. No.	Details	Readings
1	Weight of Aggregate Sample (W_1)	320 gm
2	Weight Passing 2.36 mm Sieve (W_2)	60 gm
3	Aggregate Impact Value ($W_2/W_1 \times 100$)	18.75%

Aggregate Impact Value Result = 18.75%

Marshall Stability Test

Marshall Stability Test is carried out to determine the strength and stability characteristics of bituminous mix. Aggregates, bitumen and Calcium Carbonate were mixed thoroughly and specimens were prepared using Marshall moulds. The specimens were compacted, conditioned in a water bath at 60°C and tested in a Marshall Stability Machine.

Figure 2.7 Marshall Stability Test

3.3.5 Marshall Stability Results

Table 3.5 Marshall Stability Results

Calcium Carbonate (%)	Average Stability (kN)
0	9.20
2	10.40
4	11.80

6	13.10
8	12.20

3.3.6 Flow Value Results

Table 3.6 Flow Value Results

Calcium Carbonate (%)	Flow Value (mm)
0	3.8
2	3.6
4	3.4
6	3.2
8	3.5

3.3.7 Bulk Density Results

Table 3.7 Bulk Density Results

Calcium Carbonate (%)	Weight (g)	Volume (cm ³)	Bulk Density (g/cc)
0	1161	502.58	2.31
2	1171	502.58	2.33
4	1181	502.58	2.35
6	1191	502.58	2.37
8	1176	502.58	2.34

3.3.8 Air Voids Results

Table 3.8 Air Voids Results

Calcium Carbonate (%)	Maximum Specific Gravity	Bulk Specific Gravity	Air Voids (%)
0	2.42	2.31	4.5
2	2.43	2.33	4.2
4	2.44	2.35	3.9
6	2.46	2.37	3.7
8	2.44	2.34	4.0

Figure 2.8 Preparation of Bituminous Mix

Figure 2.9 Remove Specimen

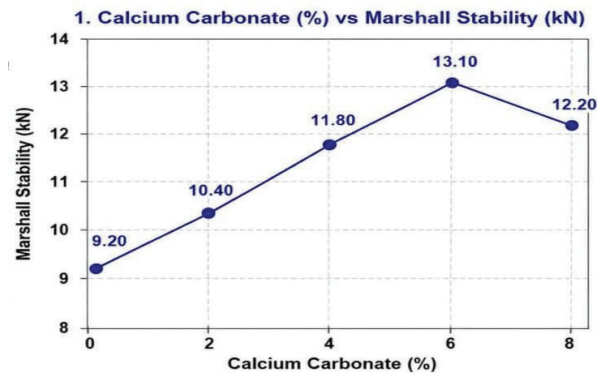
Figure 2.10 Measure Specimen Height

Figure 2.11 Marshall Stability Testing

Figure 2.12 Marshall Stability Testing

RESULTS AND DISCUSSION

Effect of Calcium Carbonate on Marshall Stability



Calcium Carbonate (%) vs Marshall Stability (kN)

The graph shows the effect of Calcium Carbonate (CaCO_3) percentage on Marshall Stability of bituminous mix.

The X-axis represents Calcium Carbonate content (%) added in the mix. The values used are 0%, 2%, 4%, 6%, and 8%.

The Y-axis represents Marshall Stability (kN). Stability indicates the load carrying capacity or strength of the bituminous mix.

At 0% Calcium Carbonate, Marshall Stability was found to be 9.20 kN. This is the stability of the conventional mix without additive.

At 2% Calcium Carbonate, Stability increased to 10.40 kN. This indicates improvement in bonding and strength.

At 4% Calcium Carbonate, Stability further increased to 11.80 kN. The mix became stiffer and stronger.

At 6% Calcium Carbonate, the maximum stability obtained was 13.10 kN. This was found to be the optimum percentage of Calcium Carbonate in the present study.

At 8% Calcium Carbonate, Stability decreased to 12.20 kN. Excess additive may reduce proper binding and performance.

Overall Trend

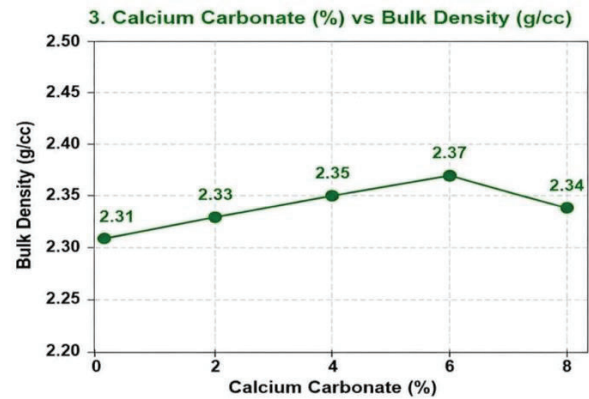
Marshall Stability increased gradually from 0% to 6% Calcium Carbonate and then decreased at 8%.

Conclusion

Addition of Calcium Carbonate improved Marshall Stability up to an optimum value. From the graph, 6%

Calcium Carbonate provided the best performance with the highest stability value of 13.10 kN.

Effect of Calcium Carbonate on Bulk Density



Calcium Carbonate (%) vs Bulk Density (g/cc)

The graph shows the effect of Calcium Carbonate (%) on the Bulk Density of bituminous mix used in Marshall Stability testing.

The X-axis represents the percentage of Calcium Carbonate added to the mix. Values used are 0%, 2%, 4%, 6%, and 8%.

The Y-axis represents Bulk Density (g/cc). The unit used is gram per cubic centimeter.

What is Bulk Density?

Bulk Density is calculated as:

Bulk Density = Mass of Compacted Mix / Total Volume of Mix

It indicates how dense and compact the bituminous mix is.

At 0% Calcium Carbonate, Bulk Density was 2.31 g/cc. This is the density of the conventional mix without any additive.

At 2% Calcium Carbonate, Bulk Density increased to 2.33 g/cc. This shows improvement in compaction and filling of voids.

At 4% Calcium Carbonate, Bulk Density further increased to 2.35 g/cc. The mix became denser and more compact.

At 6% Calcium Carbonate, the maximum Bulk Density of 2.37 g/cc was obtained. This indicates the best packing and bonding between aggregates and bitumen.

At 8% Calcium Carbonate, Bulk Density decreased slightly to 2.34 g/cc. Excess filler may reduce proper compaction.

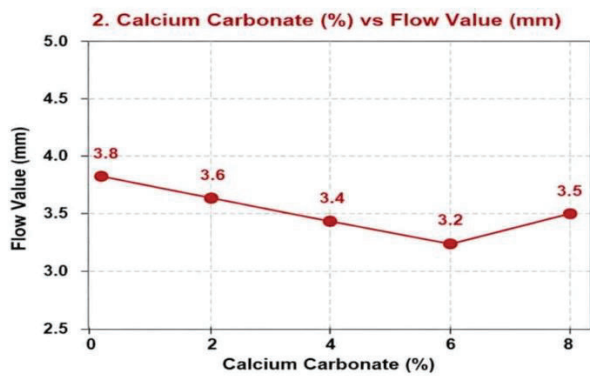
Overall Trend

Bulk Density increased gradually from 0% to 6% and then decreased at 8%.

Conclusion

Addition of Calcium Carbonate improved the Bulk Density of bituminous mix up to an optimum level. The best result was obtained at 6% Calcium Carbonate, where the mix became more compact, dense, and stable. Excess addition beyond this level slightly reduced performance.

Effect of Calcium Carbonate on Flow Value



Calcium Carbonate (%) vs Flow Value (mm)

The graph shows the effect of Calcium Carbonate (%) on the Flow Value (mm) of the bituminous mix in the Marshall Stability test.

The X-axis represents the percentage of Calcium Carbonate added to the mix. Values used are 0%, 2%, 4%, 6%, and 8%.

The Y-axis represents the Flow Value (mm). The unit used is millimeter (mm).

What is Flow Value?

Flow Value is the deformation of the bituminous specimen at the time of maximum load during the Marshall Stability test.

Importance of Flow Value

Flow Value indicates the flexibility and plasticity of the bituminous mix.

High Flow Value indicates that the mix becomes too soft.

Low Flow Value indicates that the mix becomes too stiff.

An optimum Flow Value provides balanced flexibility and stability.

At 0% Calcium Carbonate, Flow Value was 3.8 mm. This is the conventional mix without additive and shows comparatively higher deformation.

At 2% Calcium Carbonate, Flow Value decreased to 3.6 mm. This indicates improved stiffness and reduced deformation.

At 4% Calcium Carbonate, Flow Value further decreased to 3.4 mm. The mix became more stable and resistant to deformation.

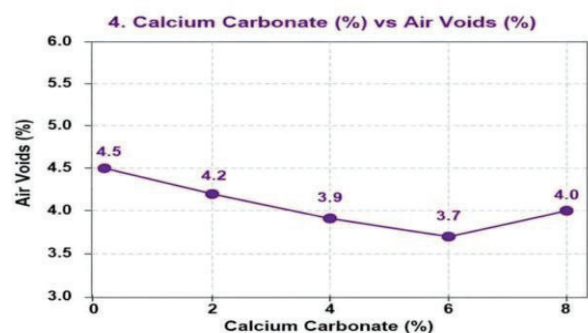
At 6% Calcium Carbonate, the minimum Flow Value of 3.2 mm was obtained. This indicates optimum stiffness and best resistance against deformation.

At 8% Calcium Carbonate, Flow Value increased slightly to 3.5 mm. Excess additive may reduce flexibility balance and affect uniformity of the mix.

Conclusion

Addition of Calcium Carbonate reduced the Flow Value and improved stiffness and stability of the bituminous mix up to an optimum level. The best performance was observed at 6% Calcium Carbonate, where the mix showed minimum deformation and maximum stability.

Effect of Calcium Carbonate on Air Voids



Calcium Carbonate (%) vs Air Voids (%)

The graph shows the effect of Calcium Carbonate (%) on the Air Voids (%) in the bituminous mix during Marshall Stability testing.

The X-axis represents the percentage of Calcium Carbonate added to the mix. Values used are 0%, 2%, 4%, 6%, and 8%.

The Y-axis represents Air Voids (%) present in the compacted bituminous mix.

What are Air Voids?

Air Voids are the small empty spaces present between aggregates in the compacted bituminous mix.

Air Voids (%) = (Volume of Air Spaces / Total Volume of Mix) × 100

At 0% Calcium Carbonate, Air Voids were 4.5%. This is the conventional mix without additive and contains comparatively more empty spaces.

At 2% Calcium Carbonate, Air Voids decreased to 4.2%. This indicates that Calcium Carbonate started filling the voids between aggregates.

At 4% Calcium Carbonate, Air Voids further reduced to 3.9%. The mix became denser and more compact.

At 6% Calcium Carbonate, Air Voids of 3.7% were obtained. This shows the best compaction and aggregate packing.

At 8% Calcium Carbonate, Air Voids increased slightly to 4.0%. Excess filler may disturb proper compaction and uniformity of the mix.

Important Observation

Lowest Air Voids = 3.7%

Highest Marshall Stability = 13.10 kN

Both occurred at 6% Calcium Carbonate, indicating optimum performance.

Conclusion

Addition of Calcium Carbonate reduced Air Voids and improved compaction of the bituminous mix up to an optimum level. The best result was obtained at 6% Calcium Carbonate, where the mix showed minimum voids and maximum stability.

Discussion

Marshall Stability

The conventional bituminous mix (0% CaCO₃) showed a stability value of 9.20 kN. Stability increased continuously with the addition of Calcium Carbonate. The maximum stability of 13.10 kN was obtained at 6% CaCO₃. The increase in stability indicates better bonding between bitumen and aggregates. At 8% CaCO₃, stability decreased to 12.20 kN, showing that excess additive may

reduce performance. Therefore, 6% CaCO₃ was found to be the optimum content for maximum strength.

Flow Value

Flow Value decreased from 3.8 mm to 3.2 mm with increasing additive content up to 6%. Lower Flow Value indicates higher stiffness and better resistance to deformation. The mix became more stable under traffic loading. At 8% additive content, Flow Value slightly increased to 3.5 mm. This indicates that excessive additive may affect the flexibility of the mix.

Bulk Density

Bulk Density increased from 2.31 g/cc to 2.37 g/cc. Higher density indicates better compaction of the mix. Calcium Carbonate acted as a filler material and reduced internal voids. Better compaction leads to improved durability and strength. Maximum density was achieved at 6% CaCO₃.

Air Voids

Air Voids decreased from 4.5% to 3.7%. Reduction in Air Voids indicates improved packing of aggregate particles. Lower voids reduce water penetration and moisture damage. Improved internal structure increases pavement life. A slight increase in Air Voids at 8% additive content was observed.

Overall Performance

Addition of Calcium Carbonate improved all important properties of the bituminous mix. Marshall Stability and Bulk Density increased, while Flow Value and Air Voids decreased. The best overall performance was obtained at 6% Calcium Carbonate content.

CONCLUSION

The present study entitled "Early Strength in Bitumen Using Chemical Admixtures" was carried out to investigate the effect of Calcium Carbonate as a chemical admixture on the engineering properties of bituminous mixes. Different percentages of Calcium Carbonate, namely 0%, 2%, 4%, 6%, and 8%, were incorporated into the bituminous mix and evaluated using Marshall Stability, Flow Value, Bulk Density, and Air Voids tests.

The experimental results revealed that the incorporation of Calcium Carbonate significantly improved the performance characteristics of the bituminous mix. Marshall Stability increased from 9.20 kN for the conventional mix to 13.10 kN at the optimum dosage,

indicating a considerable enhancement in load-carrying capacity and strength. The Flow Value decreased with increasing Calcium Carbonate content, demonstrating improved stiffness and resistance to deformation under traffic loading. Furthermore, Bulk Density increased due to improved compaction and aggregate packing, while Air Voids decreased, resulting in enhanced durability and reduced susceptibility to moisture damage.

Among all the mixtures tested, the bituminous mix containing 6% Calcium Carbonate exhibited the best overall performance. This mix achieved the highest Marshall Stability, optimum Flow Value, maximum Bulk Density, and minimum Air Voids. Beyond this percentage, a slight reduction in performance was observed, indicating that excessive additive content may adversely affect the properties of the bituminous mix.

Based on the results obtained from this investigation, it can be concluded that Calcium Carbonate is an effective chemical admixture for improving the early strength and performance of bituminous pavements. The optimum dosage was found to be 6% by weight of the mix. The addition of Calcium Carbonate enhanced strength, stability, compaction characteristics, and durability of the pavement. Therefore, the use of Calcium Carbonate is recommended for the construction of stronger, more durable, and cost-effective flexible pavements.

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