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Optimization of Recycled Asphalt Aggregate Treatment for High-Strength Prepacked Concrete: Influence of Immersion Duration and Replacement Ratio

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ABSTRACT- This study systematically investigates the use of gasoline-treated recycled asphalt aggregates in high-strength prepacked concrete, focusing on the combined effect of the aggregate replacement ratio and solvent immersion duration. Asphalt aggregates were immersed in gasoline for 2, 4, and 8 h and used to replace natural coarse aggregate at 25-100%. The compressive strength was evaluated at 7 and 28 days, whereas the tensile strength was assessed at 28 days. The results revealed that the mechanical performance was governed not only by the asphalt content but also by the duration of gasoline immersion, which has rarely been quantified in pre-packed concrete systems. While increasing asphalt content led to progressive strength reductions, the prepacked technique significantly mitigated strength loss at later ages, reducing the 28-day compressive strength reductions to approximately 10-24% at 25-50% replacement. In contrast, prolonged immersion caused additional deterioration, with tensile strength losses exceeding 30% at high replacement levels. Among all the conditions, 2 h of gasoline immersion consistently provided optimum performance, achieving effective contaminant removal while preserving aggregate integrity. The novelty of this study lies in identifying an optimum solvent treatment window for recycled asphalt aggregates within a high-strength prepacked concrete framework, demonstrating that excessive treatment is detrimental and that controlled immersion enables the sustainable use of asphalt aggregates without severe mechanical penalties.

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1. Introduction

High-strength concrete (HSC) is usually acknowledged as concrete with a compressive strength above 60 MPa and advanced applications with compressive strengths of up to 80-120 MPa [1]. HSC is a fundamental component of modern structural engineering [2]. It is applied in the construction of high-rise buildings, long-span bridges, nuclear containment structures, and offshore structures. HSC is applied in these structures because of its high strength-to-weight ratio [3]. Compared to normal-strength concrete, HSC allows the construction of smaller, more efficient, and more durable concrete members [4]. Previous research concluded that HSC can result in up to 25-35% reductions in structural dead loads [5] . This allows the construction process to be more efficient and cost-effective [6]. The improvements in HSC strength are attributed to the use of low water-to-binder ratios (often below 0.30), high cement content, and high volumes of supplementary cementitious materials, such as silica fume and fly ash. Quality and strength enhancement modifiers improve the compressive strength and permeability, whereas the HSC microstructure becomes denser and brittle [7]. Numerous experimental studies on HSC microstructures have shown that, compared to conventional concrete, HSC has 40-60% less strain capacity at failure [8]. This indicates that HSC is more likely to experience sudden, brittle fractures. Furthermore, the autogenous shrinkage values in HSC have been shown to significantly increase the possibility of premature cracking, owing to values reported to be around 500 micro strains, which is approximately double the micro strain measurement of normal-strength concrete. Understanding the limitations of HSC has inspired research aimed at improving the ductility, crack resistance, and energy absorption capacity of HSC while maintaining its compressive strength. Modified or alternative materials that enhance the flexibility and crack control of high-strength concrete have become an important focus area in advanced concrete research [9, 10].

The unique viscoelastic characteristics of asphalt-based materials and their ability to resist moisture penetration consistently make them an attractive choice as modifiers in cementitious composites. Owing to the temperature-dependent mechanical properties of asphalt, it can dissipate energy and accommodate deformation better than rigid cement phases [10]. However, untreated asphalt in cementitious systems demonstrates poor compatibility, characterized by phase separation, poor interfacial bonding, and a reduction in compressive strength [11]. Heat treatment of asphalt has been suggested to mitigate these problems [12]. Thermal treatment of asphalt at temperatures between 120°C and 180°C has been shown to reduce the viscosity of asphalt by up to 60% and improve the molecular characteristics that enhance the dispersion of asphalt in cement matrices. The adhesion of heat-treated asphalt to cement hydration products, particularly calcium silicate hydrate (C-S-H) gel, was improved [13].

In the past decade, numerous experimental studies have been conducted on the mechanical performance of high-strength concrete with heat-treated asphalt [14]. Research suggests that heat-treated asphalt, in small proportions of approximately 2-6% by weight of cement, can considerably enhance some tensile-related properties while still retaining a high level of compressive strength. Studies have noted compressive strength reductions in the range of 5-12% compared to the control HSC mixes [15]. These reductions in compressive strength, when balanced with improvements in the tensile strength and other performance markers of the concrete mixes, make the reductions more acceptable. Additionally, asphalt's crack-bridging and stress-relaxation properties have been identified as the main contributors to the observed improvements in splitting tensile strength and flexural strength of up to 30%. Improvements of up to 40% in the fracture energy are indicative of significant enhancements in ductility and post-cracking behavior [16].

Regarding the sustainability initiatives of the construction sector, the application of heat-treated asphalt in high-strength concrete, in addition to performance improvements, is a notable contributor. Around 7-8 % of global CO_2 emissions stem from cement production [17]. Therefore, initiatives that reduce the need for cement and/or increase the efficiency of the materials used are of paramount importance from an environmental standpoint. Numerous researchers have reported that the use of asphalt, and particularly the use of reclaimed asphalt, can reduce the total binder volume by up to 10 percent, at no risk to the performance of the structure [18]. Compared to traditional HSC, asphalt-modified HSC has been reported to have an 8–15 percent lower carbon footprint. However, existing studies indicate that the optimization of asphalt content, heat treatment, and mixing is still in the preliminary stages. There is a significant degree of variation in the strength, durability, and workability associated with changes in asphalt content, thermal treatment temperature, and curing duration. As a result, considerable experimental work is required to formulate design standards [19].

Prepacked concrete is a type of concrete in which coarse aggregates are first positioned in the formwork, and a cementitious grout is then injected to fill the gaps between the aggregates [20]. This method is fundamentally different from standard concrete placement and offers several structural and durability benefits, particularly in situations requiring high density, low shrinkage, and superior bonding [21]. Prepacked concrete has been extensively utilized in large structural components, underwater construction, repair activities, and in heavily reinforced areas where the typical placement of concrete is difficult or segregation is likely. Studies have shown that prepacked concrete can achieve compressive strength levels comparable to, and in some instances greater than, those of conventional concrete. Strength reports range from 40 MPa to 90 MPa and depend on the density of the grout composition and aggregate packing [22]. One of the primary benefits of prepacked concrete is the reduced drying and autogenous shrinkage, which can be 30%-50% lower than that of traditional concrete owing to the reduced paste volume and constricted aggregate skeleton. Furthermore, the preplaced aggregate structure resulted in better load transfer and lower cracking potential. Durability studies have attributed the improved resistance of prepacked concrete to permeability and chemical attack to the dense aggregate structure and controlled grout penetration. These traits exemplify prepacked concrete as a high-performance and durable solution for challenging construction scenarios [23].

This study investigated the feasibility of using recycled asphalt as a partial and full replacement of coarse aggregates in prepacked concrete at replacement levels of 25%, 50%, 75%, and 100%. This study aims to evaluate the influence of recycled asphalt on the mechanical and durability properties of prepacked concrete and identify optimal replacement ratios that balance performance and sustainability. The findings are expected to contribute to the effective reuse of asphalt waste, reduce reliance on natural aggregates, and support the development of sustainable pre-packed concrete applications.

2. EXPERIMENTAL PROGRAM

2.1. Raw materials

Ordinary Portland cement (OPC) of strength class 52.5 was used as the main binder in this study because of its high strength development, which is suitable for high-strength concrete applications. Silica fume was incorporated as a supplementary cementitious material to improve the particle packing density and enhance the interfacial transition zone (ITZ) through its pozzolanic activity. Natural sand was used as a fine aggregate in the grout mixture. The sand was clean, well-graded, and free from organic impurities, ensuring good workability and adequate flowability of the grout required for the prepacked concrete. Dolomite was used as the natural coarse aggregate because of its high mechanical strength and angular particle shape, providing an effective aggregate skeleton and improved interlocking within the prepacked concrete system. A polycarboxylate-based superplasticizer was employed to achieve the required grout fluidity at a low water-to-binder ratio, without segregation. Potable tap water, free of harmful substances, was used for mixing and curing to ensure consistent hydration and strength development.

2.2. Pretreatment of asphalt

For this study, recycled asphalt pavement (RAP) was sourced from cold milling operations performed on the top layer of damaged road pavements. In this process, a cold planer machine was used to extract damaged asphalt layers. The collected asphalt materials underwent sieve analysis and were classified into coarse and fine asphalt fractions. The coarse asphalt fraction contained particles that passed a 19 mm sieve and were retained on a 4.75 mm sieve, whereas the fine asphalt fraction contained particles that passed a 4.75 mm sieve and were retained on a 0.30 mm sieve. During the initial analysis, a considerable amount of impurities were found in the recycled asphalt, including residual asphalt and other impurities that negatively impacted the concrete. Consequently, a pretreatment process was undertaken to enhance the properties of recycled asphalt. Several samples of the coarse asphalt fraction were soaked in diesel for 2, 4, and 8-hour intervals to remove surface impurities. However, because diesel soaking was ineffective in eliminating bituminous residues, gasoline was used to substitute for diesel as shown in **Figure 1**.

In this case, coarse asphalt samples were immersed in gasoline for a total of 2h, 4h, and 8h. For additional treatments, the samples were heated for 4 h and subsequently immersed in gasoline for 8 h. Additionally, one heated sample was immersed for 2 h to study the effects of the combination of thermal and solvent treatments. The fine asphalt fraction was also divided into several samples that were treated through diesel immersion for 2, 8, and 24 h. Further samples were heated for 2 and 4 h before diesel immersion. However, the fine asphalt fraction still exhibited undesirable qualities and did not pass the experimental evaluation testing to confirm whether it could potentially replace the natural fine aggregate. Therefore, only the coarse asphalt fraction was selected for incorporation into the prepacked concrete mixtures.

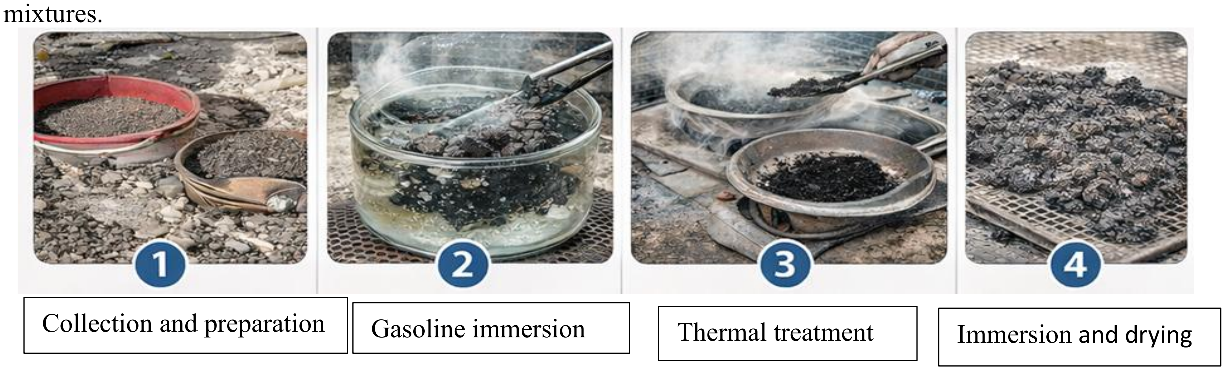

Figure 1. Asphalt treatment and reuse process

2.3. Mixing proportions

Twelve prepacked concrete mixtures were prepared in this study to evaluate the effect of recycled asphalt used as a replacement for coarse aggregates under different soaking conditions. Recycled asphalt was pre-soaked for three different durations, namely 2, 4, and 8 h, to investigate the influence of soaking time on concrete performance. Four concrete mixtures were produced for each soaking condition, resulting in a total of 12 mixtures. In all mixtures, the quantities of cement, fine aggregate (sand), and mixing water were kept constant and identical to those of the control mixture prepared with natural coarse aggregate to isolate the effect of asphalt replacement with proportions presented in **Table 1**. The coarse aggregate was replaced with recycled asphalt at four different levels: 25%, 50%, 75%, and 100% by the mass of the coarse aggregate. Accordingly, three concrete mixtures were prepared for each replacement level, corresponding to the three soaking durations. This experimental design allowed for a systematic assessment of the combined effects of asphalt content and soaking duration on the properties of the prepacked concrete.

Table 1. Mixing proportions

Material	Proportion by weight of sand
Ordinary Portland Cement (52.5)	1.00
Silica fume	0.10
Dolomite	0.8
Sand	0.4
Water	0.30
Superplasticizer	1.5% (by weight of binder)

2.4. Casting and curing

Prepacked concrete specimens incorporating recycled asphalt as a partial and full replacement of coarse aggregates were prepared using the prepacking technique. Before casting, the pretreated recycled asphalt and natural coarse aggregates were proportioned according to the specified replacement ratios and placed into the molds in a dry state to form a stable aggregate framework. The cementitious grout was prepared separately using cement, fine aggregate, silica fume, water, and superplasticizer, with the mixing proportions kept constant for all specimens to ensure consistency. The grout was mixed until a homogeneous and highly flowable consistency was achieved, which was suitable for the complete penetration of the prepacked aggregate matrix [24].

The prepared grout was then poured and injected into the molds containing the prepacked aggregates, allowing it to flow under gravity and fill the voids between the aggregate particles. Special attention was given to ensure uniform grout distribution and prevent air entrapment or segregation during casting, as shown in **Figure 2**. After casting, the specimens were maintained under ambient laboratory conditions for 24 h to allow for initial setting. Subsequently, the specimens were demolded and cured in water under controlled conditions until the designated age. This curing regime was adopted to ensure adequate hydration of the cementitious materials and to enhance the interfacial bond between the recycled asphalt aggregates and cement matrix, thereby ensuring a reliable assessment of the mechanical and durability properties of the prepacked concrete mixtures [21].

Figure 2. Casting procedures of prepacked HSC

3. RESULTS AND DISCUSSION

3.1. Compressive strength at 7 days for 2 hours treatment

After 7 days, the compressive strength results presented in **Figure 3** showed a systematic reduction in strength with the increasing replacement of natural coarse aggregate with gas-treated asphalt aggregate in high-strength prepacked concrete. The control mixture (0% replacement) attained a compressive strength of 650 kg/cm², showing the effectiveness of the prepacked system and the high-quality aggregate-grout interaction at early curing ages [25]. At a replacement rate of 25%, the compressive strength decreased slightly to 604 kg/cm², corresponding to approximately a 7.1% reduction compared to the control. This reduction indicates that at low replacement ratios, the rigid skeleton composed of natural aggregates remains dominant, whereas the treated asphalt aggregates act as a secondary component. In this range, gas immersion for 2 h is sufficient to remove surface oily residues to an acceptable level for bonding between the asphalt aggregate and cement grout, without significantly compromising early strength. The compressive strength at high replacement levels exhibited a steep decline [26]. At 50% replacement, the compressive strength dropped to 445 kg/cm², showing a reduction of approximately 31.5%. This significant decline indicates a transitional point at which the mechanical behavior of the composite is increasingly determined by the properties of the asphalt aggregates.

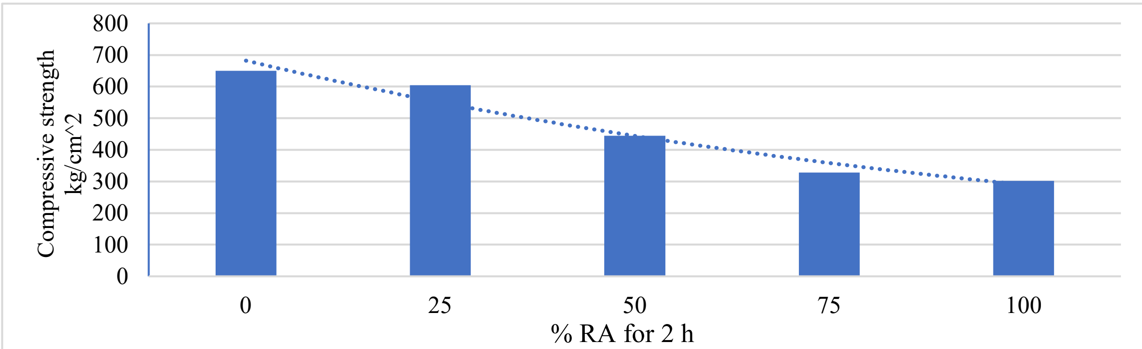

Figure 3. 7-day compressive strength for prepacked HSC treated for 2 h

3.2. Compressive strength at 7 days for 4 hours treatment

The compressive strength results after 7 days of testing, presented in **Figure 4,** showed evidence of varying levels of strength achieved by the different treatment groups, particularly as the gasoline immersion duration increased and natural coarse aggregates were substituted for asphalt aggregates. The control group achieved 650 kg/cm², proving that the prepacked concrete system is effective, as it enables the concrete to develop a considerable amount of strength at early ages.

At 25% replacement, the compressive strength dropped to 556 kg/cm², a decrease of approximately 14.5% compared to the control group. Immersion in gasoline for 2 h produced less compressive strength, but the 4-hour immersion did not correlate with adequate improvements in early-age mechanical performance [27]. While more immersion did seem to improve the removal of oily surface contaminants, it may have driven the softening and alteration of the asphalt more, resulting in less improvement in the bonding of the grout and aggregates [28].

When the replacement reached 50%, the compressive strength further declined to 520 kg/cm², which is a reduction of approximately 20.0%. The influence of the prepacked skeleton of the asphalt aggregate was most pronounced, and the mechanical response was dominated by the stiffness of the asphalt aggregates, which was lower than that of the natural aggregates. While the 4 h immersion period appears to enhance the surface condition compared to shorter immersion treatments, it still does not address the mechanical properties of the asphalt aggregates associated with moderate replacement levels. Higher replacement levels resulted in more pronounced decreases in compressive strength. At 75% and 100% replacement, compressive strength values of 308 kg/cm² and 280 kg/cm² were recorded, respectively, with strength losses of approximately 52.6% and 56.9%, respectively. At these substantial amounts of asphalt, the prepacked aggregate skeleton was largely asphalt-aggregate dominated, resulting in greater deformability and poorer load transfer characteristics [29]. Furthermore, at the 7-day early age of curing, the grout cement matrix and the interfacial transition zone (ITZ) may be immature enough not to offset the poor mechanical contribution of the asphalt aggregate and the possible unbound bitumen films.

The results demonstrate that increasing the gasoline immersion duration to 4 h does not remove the negative effects caused by a high replacement ratio of asphalt aggregates at early ages. While moderate replacement levels maintained an acceptable compressive strength, high asphalt content led to significant loss of strength. This emphasizes the need to either optimize the treatment conditions or rely on strength development at a later age to achieve satisfactory mechanical performance.

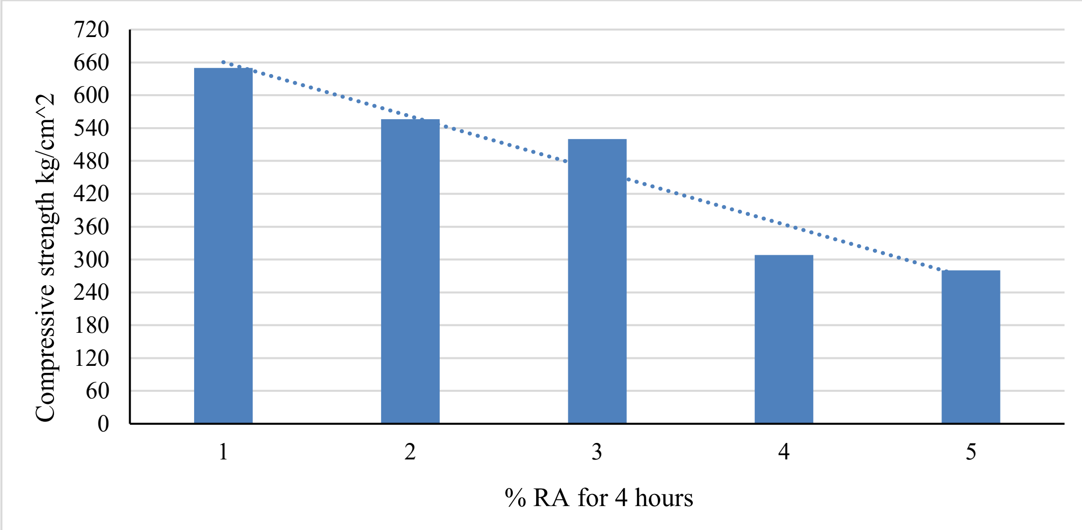

Figure 4. 7-day compressive strength for prepacked HSC treated for 4 h

3.3. Compressive strength at 7 days for 8 hours treatment

The 7-day compressive strength findings for samples immersed in gasoline for 8 h presented in **Figure 5** displayed the integrity loss in early age mechanical performance for treated asphalt aggregates as coarse aggregate replacement, increases. The control mixture strength reached 650 kg/cm². Other asphalt-containing mixtures performed lower than this, regardless of the replacement. The strength loss ratio at 25% replacement was 38.5% compared to that of the control mixture. The strength was 400 kg/cm². The strength loss ratio at 25% replacement was 38.5% compared to that of the control mixture. Strength was 400 kg/cm².

This loss shows the negative effects of gasoline immersion on the asphalt aggregates mechanical properties and surface characteristics. Asphalt binders' partial softening, increased porosity, or both, adversely affect the aggregate-cement grout bond. When the replacement ratio increased to 50%, the compressive strength further decreased to 300 kg/cm², which was a decline of approximately 53.8%. At this ratio, the detrimental effects of prolonged solvent exposure are heightened, given the increased levels of asphalt aggregates within the prepacked skeleton. There is a high level of aggregate stiffness, and the interfacial transition zone (ITZ) is weakened along with the dry grout of the cement, which results in a more pronounced loss in the structural capacity [30]. The most severe loss in strength was observed with 75% and 100% replacements, with compressive strengths of 200 kg/cm² and 172 kg/cm² (a loss of approximately 69.2% and 73.5%, respectively).

At these extreme replacement levels, the prepacked concrete system predominantly comprised asphalt aggregates, which were subjected to prolonged solvent exposure. The composite is characterized by increased deformability and, more importantly, decreased stress transfer efficiency, particularly at the 7-day early curing age, when the cementitious matrix is still in its primitive form. The results show that although gasoline immersion effectively removes oil contaminants, an excessive immersion duration (8 h) negatively affects the early age compressive strength. Hence, a dry immersion duration exists, beyond which the adverse effects of asphalt aggregate softening and surface degradation shift the balance towards compromising contaminant removal from a benefit [31]. Therefore, gasoline immersion should not be undertaken for high-strength prepacked concrete, where early age strength is a critical performance criterion.

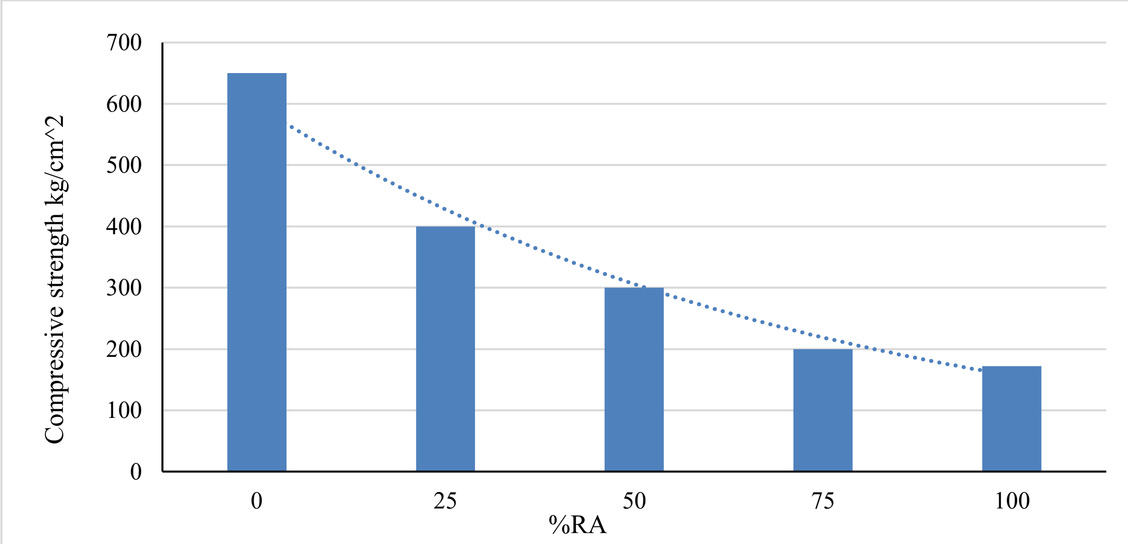

Figure 5: 7 days compressive strength for prepacked HSC treated for8h

3.4. Comparison between the compressive strength of HSC with recycled asphalt treated at different hours

The 7-day compressive strength results presented in **Figure 6** demonstrate that increasing the gasoline immersion duration from 2 h to 8 e 7-day compressive strength results demonstrated that increasing the gasoline immersion duration from 2 h to 8 h generally led to a noticeable reduction in strength for all asphalt aggregate replacement ratios. At low replacement levels (25%), short immersion (2 h) resulted in minor strength loss, whereas extending the immersion to 4 and 8 h caused progressively higher reductions, indicating that prolonged solvent exposure negatively affects early age bonding between asphalt aggregates and cement grout. At moderate replacement levels (50%), the influence of immersion duration became more pronounced, with strength losses increasing significantly at 8 h of immersion, despite relatively comparable performance between 2 h and 4 h treatments. This behavior suggests the presence of an optimum treatment duration, beyond which the adverse effects of asphalt aggregate softening and interfacial degradation outweigh the benefits of the removal of contaminants.

For high replacement ratios (75-100%), severe strength reductions were observed regardless of the immersion duration; however, the lowest compressive strength values consistently corresponded to the 8 h immersion condition. Overall, the results confirm that extended gasoline immersion is detrimental to the early age compressive strength of high-strength prepacked concrete, particularly at high asphalt contents, and generally leads to a noticeable reduction in strength for all asphalt aggregate replacement ratios. At low replacement levels (25%), short immersion (2 h) resulted in minor strength loss, whereas extending the immersion to 4 and 8 h caused progressively higher reductions, indicating that prolonged solvent exposure negatively affects early age bonding between asphalt aggregates and cement grout.

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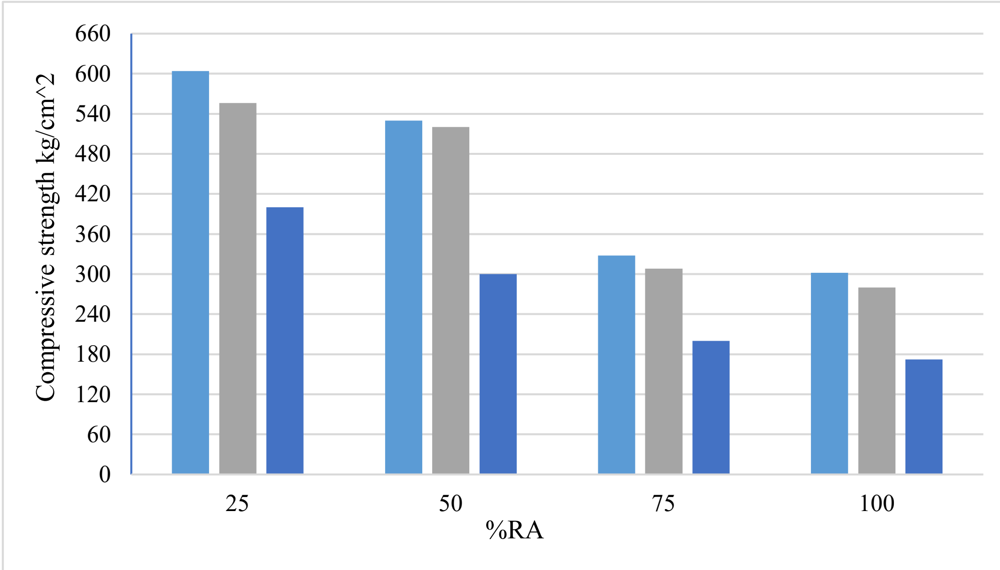

Figure 6. 7-day compressive strength for prepacked HSC treated for different hours

3.5. Compressive strength at 7 days for 2-hour treatment

The compressive strength results at 28 days presented in **Figure 7** indicate the effects of the replacement ratio of natural coarse aggregate with gasoline-treated asphalt aggregates in high-strength prepacked concrete. The reference mixture produced a compressive strength of 730 kg/cm², proving the ability of prepacked concrete systems to create dense, mechanically efficient aggregate skeletons supported by well-penetrated cement grout. The strength at the 25% replacement level was only 657 kg/cm², a 10.0% reduction overall. The loss of strength was attributed to the fact that, with such low asphalt contents, the prepacked aggregate was predominantly natural, so the stress transfer through the aggregate skeleton was not impaired. The extended curing period is associated with the continual hydration of the grout, which enhances the bond at the aggregate-grout interface, counteracting the weaker points of the elevated asphalt aggregate.

When the replacement was set to 50%, the resulting compressive strength was 554 kg/cm². This reflects a decrease of approximately 24.1%. Although a loss of strength may be significant, the prepacked system can still offer a reasonably dependable load-bearing system. This is because the grout fills the voids between the aggregates and improves the interlocking within the composite. Of course, asphalt aggregates in a greater ratio serve to diminish the overall stiffness of the aggregate skeleton, thus limiting compressive resistance, even despite the advantages of prolonged curing. At the higher replacement levels of 75% and 100%, the resulting compressive strengths of 424.5 kg/cm² and 375 kg/cm² reflect a strength loss of approximately 41.9% and 48.6%, respectively. At these asphalt content levels, the prepacked aggregate framework is readily dominated by asphalt aggregates, and the lowered elastic modulus and bituminous residual surface weaken the interfacial transition zone (ITZ). Although the 28-day curing cycle enhances the densification of the grout and improves the bonding at the aggregate-matrix interface compared to the early stage, it does not fully offset the increased asphalt skeleton of the lower stiffness and diminished load-bearing capability. The results indicate that the prepacked concrete technique is critical for reducing strength loss owing to grout penetration, interlocking, and hydration in the grout. Furthermore, although curing for a prolonged period is, on the whole, beneficial for reducing the relative strength loss, when the comparison is made to the results at 7 days, high replacement ratios of asphalt aggregate continue to negatively impact compressive strength. This underscores the need to balance the replacement level and treatment conditions when incorporating treated asphalt aggregates into high-strength prepacked concrete.

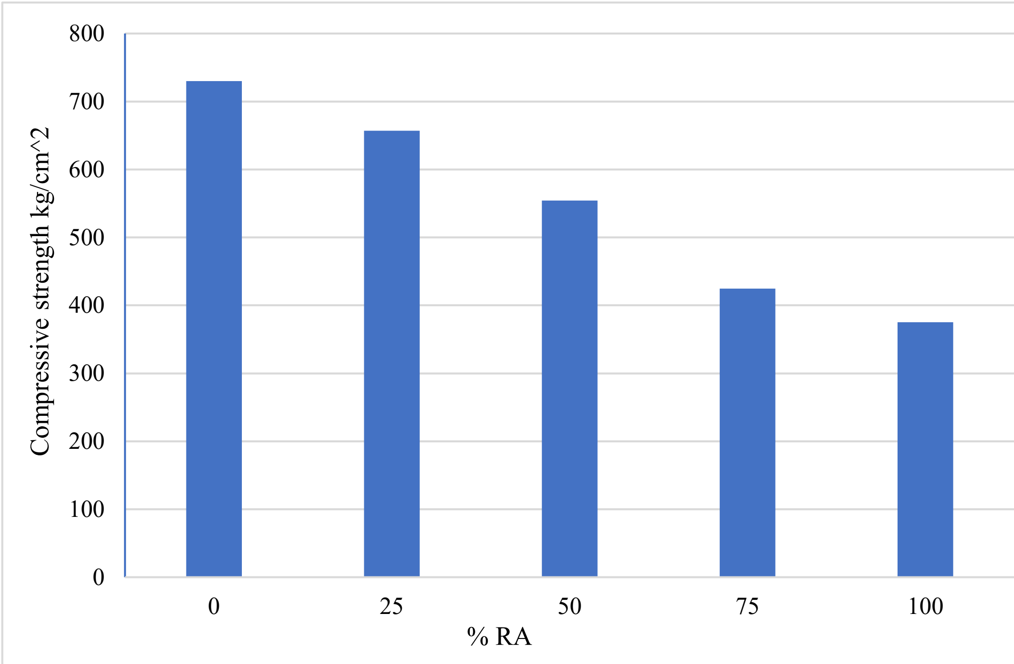

Figure 7. 28-day compressive strength for prepacked HSC treated for 2 h

3.6. Compressive strength at 28days for 4 hours treatment

After 4 h of immersion in gasoline, the 28-day compressive strength results presented in **Figure 8** demonstrated that as the coarse natural aggregate was substituted with the treated asphalt aggregate, the strength was consistently reduced. The control mixture achieved 730 kg/cm², validating the capability of the high-strength prepacked concrete system to create a dense aggregate skeleton and a sufficiently hydrated cement grout at later ages. Within the moderate strength loss range are the compressive strength values of 570 kg/cm² and 531 kg/cm² at 25% and 50%, respectively. These results indicate that the prepacked technique, at least to some extent, improves grout penetration and aggregate interlocking to counter the negative effects of asphalt aggregates after long-term curing. However, the reduced stiffness of asphalt aggregates continues to constrain the compressive resistance of concrete. More notable drops in compressive strength were recorded at higher replacement ratios (75-100%), where the results were 417 kg/cm² and 320 kg/cm², respectively. Within these ranges, the prepacked skeleton is overrun by asphalt aggregates, resulting in suboptimal load transfer efficiency, even with improved grout densification at 28 days. The data suggests that 4 h gasoline immersion, coupled with the prepacked concrete system, enables adequate strength development at low to moderate replacement levels. However, excessive asphalt aggregate content continues to negatively affect compressive strength, even with increased curing durations.

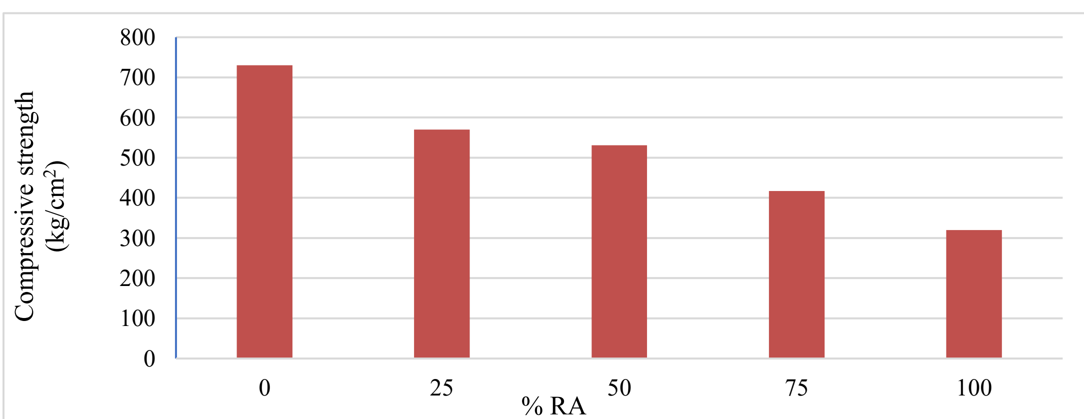

Figure 8. 28-day compressive strength for prepacked HSC treated for 4 h

3.7. Compressive strength at 28days for 8 hours treatment

The compressive strength results after 28 days for specimens immersed in gasoline for 8-h presented in **Figure 9** demonstrated a distinct decrease in strength as the natural coarse aggregate replacement with treated asphalt aggregate increased. The control mixture obtained 730 kg/cm², which shows the positive result of the extended curing on the prepacked concrete system, which solidified a dense aggregate-grout structure. With 25% and 50% replacement, the compressive strength values are 504 kg/cm² and 468 kg/cm², respectively. Extended curing did not positively affect the strength owing to the longer immersion period, which was attributed to the asphalt aggregate surface being negatively impacted and the aggregate-grout bonding being prepacked. The lowest compressive strength values of 414 and 300 kg/cm² were obtained with a higher replacement of levels (75-100%). Asphalt aggregate is the main mineral constituent of the prepacked skeleton at this level, and the combination of lower aggregate stiffness and surface degradation due to prolonged immersion results in a lack of efficient load transfer, despite improved grout densification after 28 d. The results indicate that while the prepacked concrete method improves strength development over time, prolonged immersion in gasoline (8 h) is harmful to the compressive strength, particularly when the asphalt aggregate content is high.

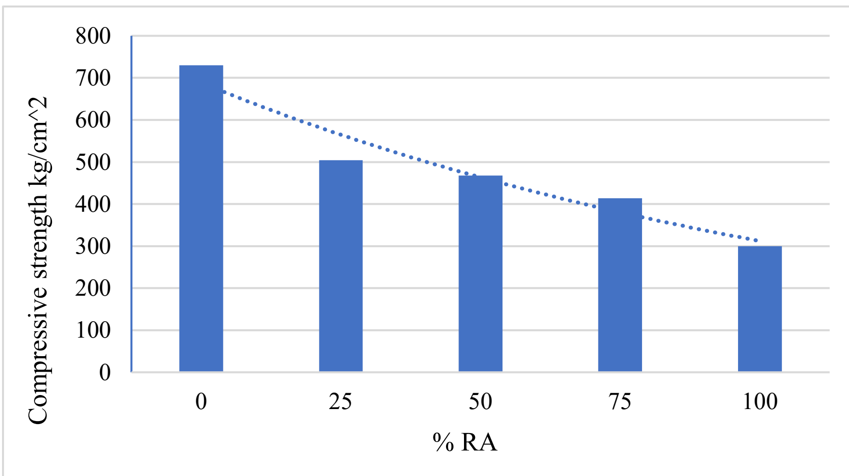

Figure 9. 28-days compressive strength for prepacked HSC treated for 8 h

3.8. Comparative Discussion of Gasoline Immersion Duration on 28-Day Compressive Strength

The results for compressive strength after 28 days, presented in **Figure 10**, show that the duration of immersion in gasoline has a secondary but noticeable effect on the mechanical properties of high-strength prepacked concrete with treated asphalt aggregates. For all replacement ratios, increasing the immersion period from 2 to 8 h decreased the compressive strength of concrete. At 28 days, the compressive strength decreased the most in 2 h, but it did decrease in 8 h. For replacement ratios of 25-50 percent, the specimens that were treated for 2 h showed strength. In 4 hours, the compression strength, and in 8 hours, the compression strength was the lowest. These data indicate that solid immersion was probably sufficient to remove all surface particle contaminants without damaging the surface of the asphalt aggregate. It is also probable that the surface of the asphalt aggregate is softened, and micro-surface degradation occurs, effectively decreasing the surface of the aggregate, resulting in a negative effect on the bonding surface of the aggregate, limiting the concrete to set rock and developing negative impacts on future states. For replacement ratios of 75-100%, 8 h of immersion in gasoline still showed the lowest compressive strength, despite all of the other immersion periods being comparable. The mechanical properties are primarily influenced by the prepacked aggregate skeleton, and the asphalt aggregate is dominant. The improved grout densification and extended curing do not sufficiently balance the lowered aggregate stiffness.

The analysis shows that the prepacked concrete system improves strength development at 28 days owing to effective grout penetration and aggregate interlocking; however, immersion in excess gasoline for prolonged periods is still negative. In terms of performance, 2 h of immersion provided the best balance, especially for high-strength concrete applications, where natural coarse aggregates were partially replaced by treated asphalt aggregates.

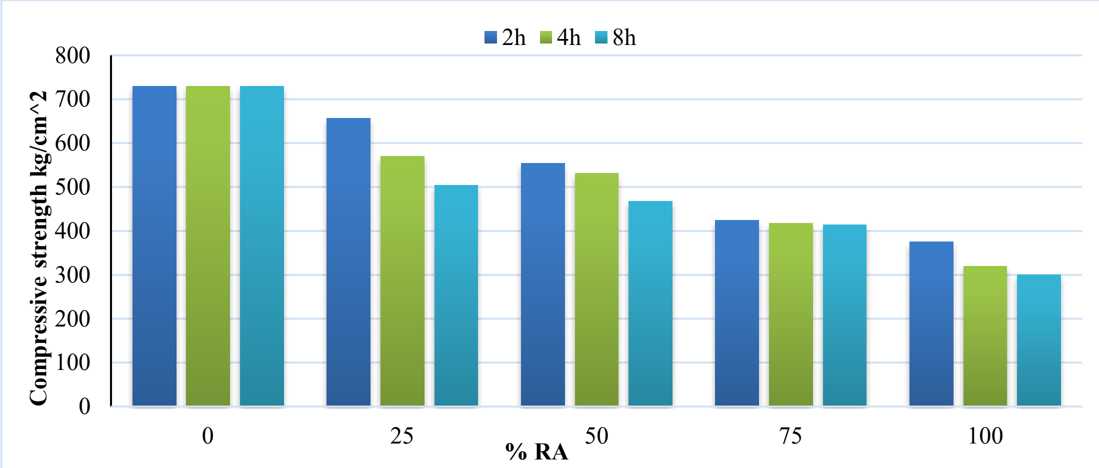

Figure 10. 28-day compressive strength for prepacked HSC treated for different hours

3.9. splitting tensile strength at 28 Days (2 h Gasoline Immersion)

The tensile strength results after 28 days for the samples treated with 2 h of gasoline immersion, presented in **Figure 11**, showed a gradual reduction with an increase in the replacement of natural coarse aggregate by treated asphalt aggregate. The highest tensile strength was recorded at 25% replacement (119 kg/cm²), suggesting that there is little impairment of tensile performance with the incorporation of asphalt aggregate at this level in high-strength prepacked concrete. At 50% and 75% replacement, the tensile strength decreased moderately by approximately 12-18%, which reflects the increased impact of asphalt aggregate on the initiation and propagation of cracks. The prepacked concrete system improves the penetration of the grout and interlocking of the aggregates; however, the tensile behavior is still highly dependent on the quality of the interface between the aggregate and grout. The lower stiffness of asphalt aggregates, combined with the bituminous film, decreases the interfacial bonding and increases the microcracking of the concrete during tensile loading [32]. At 100% replacement, there was a significant reduction in the tensile strength. The tensile strength recorded was 41% less than that of the 25% mixture. The prepacked aggregate skeleton was completely dominated by asphalt aggregates at this level, and as a result, there was weak crack bridging and little tensile stress resistance. Even with the advantages of prepacking and extended curing, the tensile strength is still much more affected than the compressive strength because the prepacked technique takes more of a toll on interfacial defects. In summary, the findings verify that although the concrete system retains reasonable tensile strength at low to moderate replacement rates after 2 h of gasoline immersion, high asphalt aggregate proportions significantly diminish the tensile strength at 28 days.

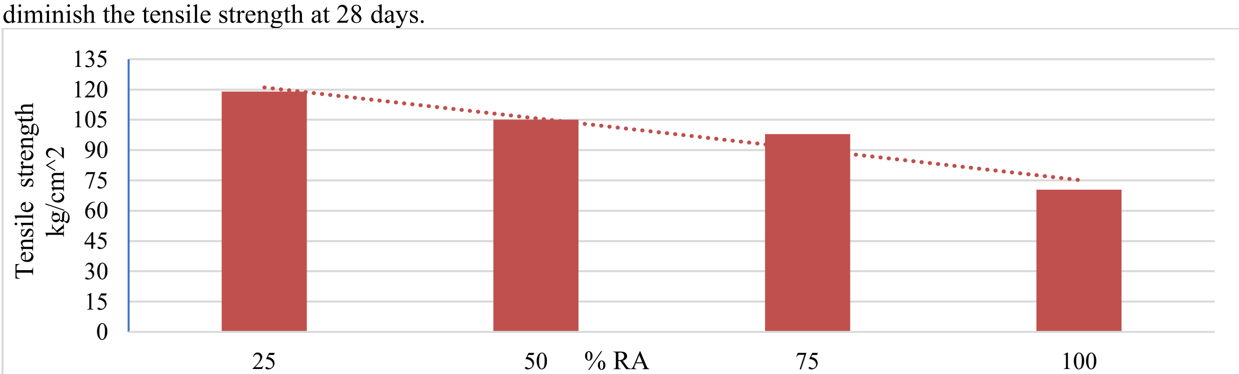

Figure 11. Splitting tensile strength for prepacked HSC treated for 2 h

3.9. Splitting tensile strength at 28 Days (4 h Gasoline Immersion)

The tensile strength after 28 days for the specimens immersed in gasoline for 4 h, as presented in **Figure 12**, showed a systematic decrease with a higher substitution of natural coarse aggregate for asphalt aggregate. The mixture with 25% asphalt aggregate achieved the highest tensile strength (96.9 kg/cm²) and was considered the reference for this group. At 50% replacement, the tensile strength was 84.3 kg/cm², which is a decrease of 13.0% from the 25% mixture. This decrease shows that the prepacked high-strength concrete system can at least partially overcome the negative effects of asphalt aggregates for the filling and interlocking of aggregates with asphalt aggregates at lower to moderate levels of replacement. At 75% replacement, a greater reduction was observed, where the tensile strength decreased to 68.6 kg/cm², which is a reduction of approximately 29.2%. This increase reflects the greater effect of asphalt aggregates on the initiation and propagation of cracks, which is attributed to the lower stiffness of asphalt aggregates and bituminous surface residuals that weaken the aggregate-grout interface [33]. With 100% replacement, the tensile strength decreased further to 61.0 kg/cm², a total reduction of 37.1%. At this level, the prepacked aggregate skeleton is entirely dominated by asphalt aggregates, indicating a further reduction in the crack-bridging capability and resistance to tensile stresses. Despite the advantages of extended curing and the prepacked approach, the tensile strength reduction remains highly sensitive to the presence of interfacial defects and aggregate stiffness, making it worse than the compressive strength. The results indicate that although 4 h gasoline immersion together with the prepacked concrete system can sustain reasonable tensile performance at lower replacement levels, higher proportions of asphalt aggregates progressively increase tensile strength losses, which can be attributed to interfacial weakening and less rigid aggregates.

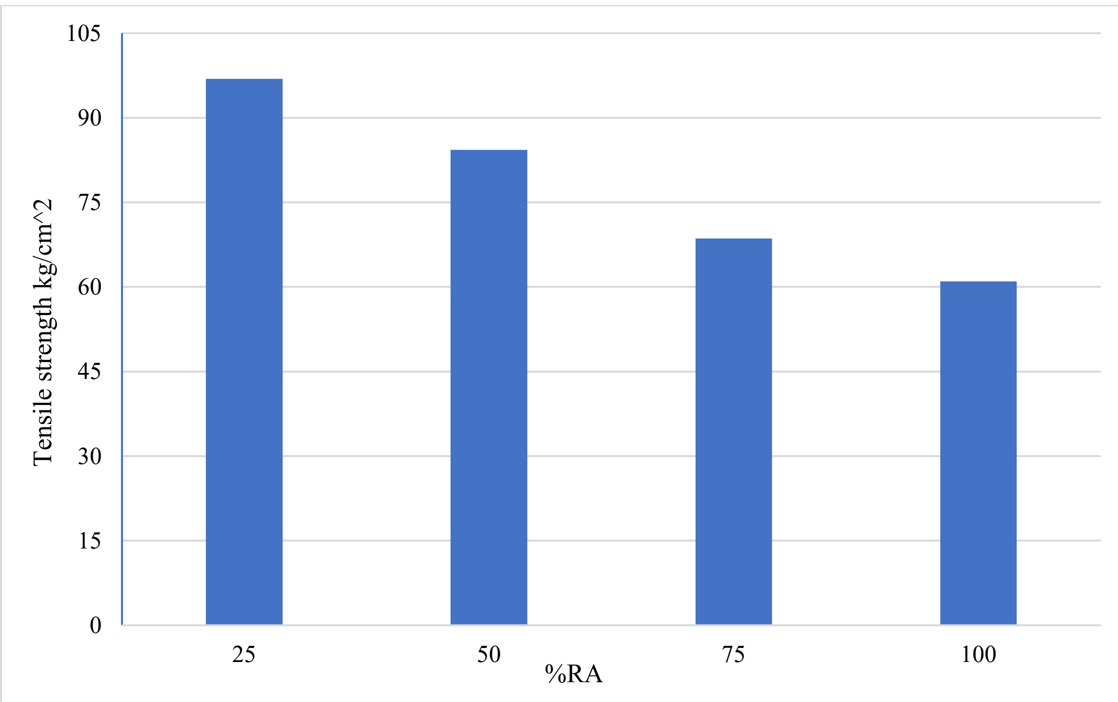

Figure 12. Splitting tensile strength for prepacked HSC treated for 4 h

3.10. Splitting tensile strength at 28 Days (8 h Gasoline Immersion)

The tensile strength results at 28 days for the specimens subjected to 8 h of gasoline immersion, presented in **Figure 13**, showed a clear and progressive reduction with increasing replacement of natural coarse aggregate by treated asphalt aggregate. The mixture containing 25% asphalt aggregate achieved the highest tensile strength (89 kg/cm²) and was therefore considered the reference for comparison for this immersion duration. At 50% replacement, the tensile strength decreased to 82 kg/cm², corresponding to a reduction of approximately 7.9% relative to that of the 25% mixture. This limited reduction suggests that, despite the prolonged immersion duration, the prepacked concrete system can still maintain reasonable aggregate interlocking and grout penetration at low to moderate replacement levels [34]. A more pronounced reduction was observed at 75% replacement, where the tensile strength dropped to 68 kg/cm², representing a decrease of approximately 23.6%. This behavior reflects the increasing dominance of asphalt aggregates within the prepacked skeleton, leading to a weaker crack-bridging capacity and reduced resistance to tensile stresses owing to the lower stiffness and residual bituminous characteristics of the asphalt aggregates. At 100%

replacement, the tensile strength further decreased to 56 kg/cm², corresponding to a total reduction of approximately 37.1% compared with the reference mixture. At this level, the prepacked aggregate framework was fully governed by asphalt aggregates, and the extended gasoline immersion duration likely exacerbated surface softening and interfacial degradation, resulting in a significant loss of tensile performance [35]. Overall, the results indicate that 8 h of gasoline immersion has a detrimental effect on the tensile strength, particularly at high asphalt aggregate contents. Although the prepacked concrete technique contributes to improved grout distribution and later-age strength development, the tensile performance remains highly sensitive to aggregate stiffness and interfacial quality [36]. Consequently, prolonged immersion durations combined with high replacement ratios are not favorable for maintaining the tensile strength in high-strength prepacked concrete.

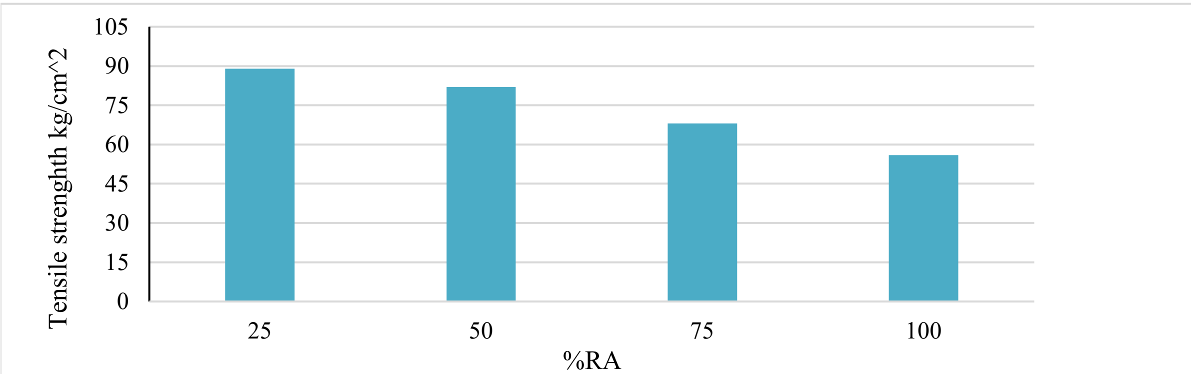

Figure 13. Splitting tensile strength for prepacked HSC treated for 8 h

3.11. Comparative Discussion of Gasoline Immersion Duration on 28-Day splitting tensile Strength

The 28-day tensile strength results presented in **Figure 14** clearly indicated that 2 h of gasoline immersion provided the optimum performance for high-strength prepacked concrete incorporating treated asphalt aggregates. For all replacement ratios, the specimens treated for 2 h consistently exhibited higher tensile strength than those treated for 4 and 8 h, while the lowest values were generally associated with 8 h of immersion.

At 25% replacement, the tensile strength decreased from 119 kg/cm² (2 h) to 96.9 kg/cm² (4 h) and 89 kg/cm² (8 h), corresponding to reductions of approximately 18.6% and 25.2%, respectively. A similar trend was observed at 50% replacement, where the tensile strength decreased from 105 kg/cm² (2 h) to 84.3 kg/cm² (4 h) and 82 kg/cm² (8 h). These results demonstrate that extending the immersion duration does not improve the tensile performance, even at moderate replacement levels.

At higher replacement ratios (75-100%), the adverse effect of prolonged immersion became more pronounced, with tensile strength losses exceeding 30% when comparing 2 h and longer immersion durations. Although the prepacked concrete system enhances grout penetration and later-age strength development, the tensile behavior remains highly sensitive to the aggregate surface condition and interfacial quality [37] .

Overall, the findings confirm that short-duration gasoline immersion (2 h) achieves the most favorable balance between contaminant removal and the preservation of asphalt aggregate integrity. Longer immersion durations (4 and 8 h) led to progressive tensile strength deterioration and are therefore less suitable for applications where tensile performance is critical.

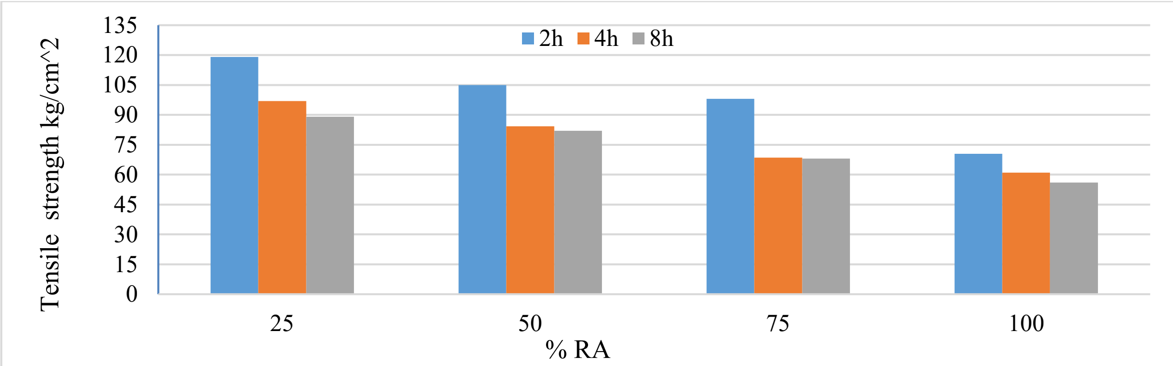

Figure 14. Splitting tensile strength for prepacked HSC treated at different hours

4. Conclusions

Based on the experimental results obtained in this study, the following conclusions were drawn: The use of gasoline-treated recycled asphalt aggregates in high-strength prepacked concrete resulted in systematic reductions in the compressive and tensile strengths, with the magnitude of reduction increasing as the replacement ratio increased. At 7 days, compressive strength losses ranged from approximately 7% at 25% replacement to more than 50% at high replacement levels, indicating that the early-age strength is strongly influenced by the stiffness of the asphalt aggregation and interfacial quality.

At 28 d compressive strength losses were reduced to approximately 10-24% at 25-50% replacement, confirming that prolonged curing and the prepacked concrete system significantly enhanced later-age strength development. Tensile strength was more sensitive than compressive strength to asphalt aggregate content and treatment duration, with strength reductions exceeding 30-40% at high replacement ratios. Increasing gasoline immersion duration from 2 hto8 h resulted in additional strength losses, with tensile strength reductions reaching up to 25% at low replacement levels, demonstrating that prolonged immersion adversely affects asphalt aggregate surface integrity. Among all investigated conditions, 2 h of gasoline immersion provided the optimum balance, achieving effective contaminant removal while minimizing strength deterioration.

The prepacked concrete technique played a critical role in mitigating strength loss by improving grout penetration, aggregate interlocking, and load transfer efficiency, particularly at later curing ages. Overall, partial replacement levels (25-50%) combined with short-duration gasoline immersion are recommended to achieve acceptable mechanical performance in high-strength prepacked concrete incorporating recycled asphalt aggregates.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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