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Effect of Recycled Rubber Particles on the Compressive Strength of Reinforced Concrete Beams Using Different Sand Sources

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Abstract
This study investigates the effect of recycled rubber particles on the compressive strength of concrete using different rubber replacement ratios (9%, 12%, and 15%) and different sand sources (Qarnilia, Sidi Al Sayeh, and Zliten) The experimental results show that.
The disposal of waste tires has become a serious environmental challenge worldwide due to their non-biodegradable nature and large accumulation rates. One of the most promising sustainable solutions is the reuse of waste tire rubber in concrete production. Effect of Rubber Particles on the Compressive Strength of Reinforced Concrete Beams.

1. Introduction

construction material in the world due to its high compressive strength, durability, and economic advantages. However, the rapid growth of construction activities has led to increased consumption of natural resources and environmental degradation. compressive strength is significantly affected by rubber content, sand type, and curing age.
The highest compressive strength was recorded for concrete containing Sidi Al Sayeh sand. The study confirms that rubberized concrete can contribute to sustainable construction while maintaining acceptable mechanical properties.
Concrete is the most widely used
One of the major environmental problems is the disposal of waste tires. Millions of tires are discarded every year, creating serious environmental concerns [4]. Recycling these tires into construction materials has become an important research area. Rubberized concrete is produced by partially replacing natural aggregates with recycled rubber particles. This material has shown improved ductility, impact resistance, and energy absorption [3,5].
However, its compressive strength is generally lower than conventional concrete due to weak bonding between rubber particles and cement paste [3].
Despite this limitation, it remains a promising material for sustainable construction applications due to its environmental benefits and improved energy absorption characteristics [5].
The aim of this study is to evaluate the effect of rubber particles on the compressive strength of reinforced concrete beams.

2. Materials and Methods

2.1 Materials

The materials used in this study include:
• Cement
• Water
• Fine Aggregate (Qarnilia, Sidi Al-Sayeh, Zliten)
• Coarse Aggregate
• Recycled Rubber Particle

Table (1) concrete mix design (per m^3)

MATERIA	Quantity (kg/m^3)
water	225
cement	450
Fine Aggregate	596.75
Coares Aggregate	1108.25

2.2 Experimental Program

Three rubber replacement ratios were used:

9% %12 15%

Specimens were tested after:

- 7 days
- 14 days
- 28 days

Compressive strength was measured using standard testing procedures.

2.3 Durability Behavior of Rubberized Concrete

Recent studies have expanded beyond compressive strength to investigate the long-term durability of rubberized concrete. It has been found that rubber particles significantly influence:

- Water absorption capacity
- Resistance to freeze - thaw cycles
- Chloride ion penetration
- Carbonation depth

Research shows that rubberized concrete tends to have higher water absorption due to increased micro-voids. However, it performs better in environments exposed to dynamic loading and vibration.

2.4 Seismic and Dynamic Performance

One of the most important modern applications of rubberized concrete is in earthquake-resistant structures. Recent experimental studies indicate that rubber particles:

- Increase damping capacity
- Reduce vibration intensity
- Improve energy dissipation under cyclic loading

This makes rubberized concrete suitable for structures in seismic zones, where flexibility is more important than high compressive strength.

2.5 Thermal and Acoustic Properties

Another important advantage of rubberized concrete is its improved insulation behavior. Thermal performance: Rubber particles reduce thermal conductivity, making concrete more resistant to heat transfer. Acoustic performance: Rubberized concrete shows improved sound absorption due to its porous structure, making it suitable for:

- Highway barriers
- Industrial building
- Urban infrastructures noise control systems.

2.6 Sustainability and Life Cycle Assessment (LCA)

Modern research emphasizes the importance of Life Cycle Assessment (LCA) when evaluating construction materials. Rubberized concrete contributes to sustainability by:

- Reducing landfill waste.
- Lowering demand for natural aggregates
- Decreasing carbon footprint of construction materials

Studies show that even partial replacement of natural aggregates with rubber can significantly reduce environmental impact over the full life cycle of concrete structures.

2.7 Failure Mechanism of Rubberized Concrete

The failure mode of rubberized concrete differs from normal concrete. In conventional concrete:

- Sudden brittle failure occurs

in rubberized concrete:

- More ductile failure
- Gradual crack propagation
- Higher deformation before collapsing

This behavior is due to the elastic nature of rubber particles, which absorb stress instead of fracturing.

3. Results and Discussion

The results of the compressive strength tests are presented in Table 2. The influence of rubber content, sand type, and curing age is discussed in detail.

Table (2) Compressive Strength result of Rubberized concrete

Curing Age	Rubber content	Sand source	Compressive Strength(Mpa)
7 Days	9%	Qarnilia	51
7 Days	9%	Sidi Al Sayeh	72
7 Days	9%	Zliten	60
14 Days	12%	Qarnilia	47
14 Days	12%	Sidi Al Sayeh	60
14 Days	12%	Zliten	42
28 Days	15%	Qarnilia	56
28 Days	15%	Sidi Al Sayeh	71
28 Days	15%	Zliten	62

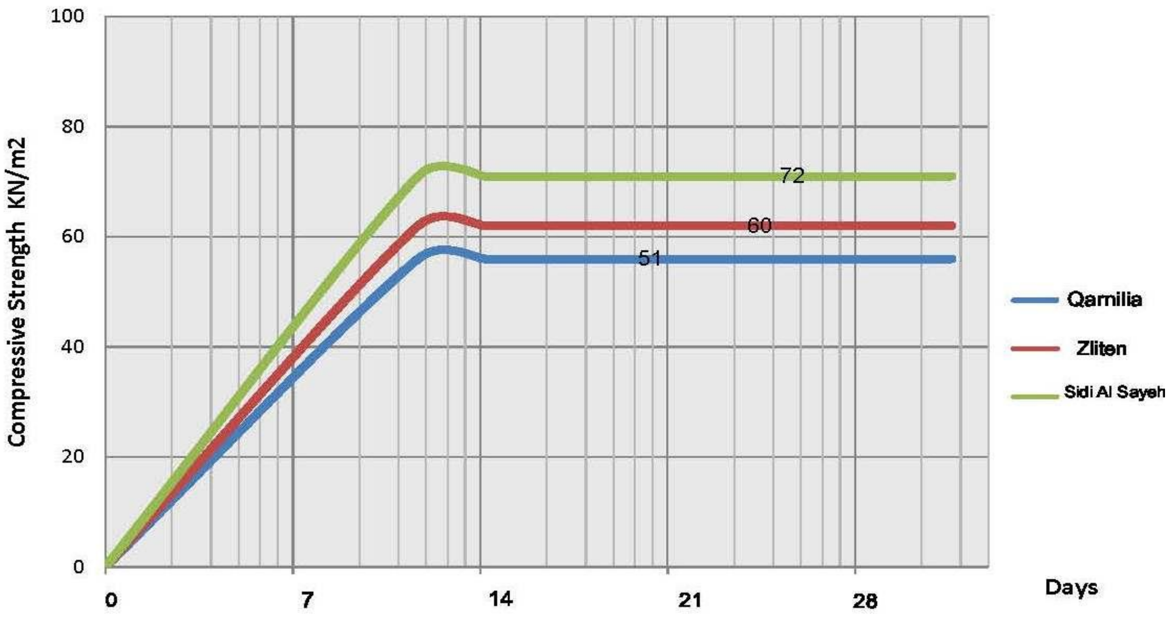

Fig (1) 9% Rubber (7days) Compressive Strength

The results show that Sidi Al-Sayeh sand achieved the highest compressive strength value of 72 MPa, while Qarnilia sand recorded the lowest value of 51 MPa

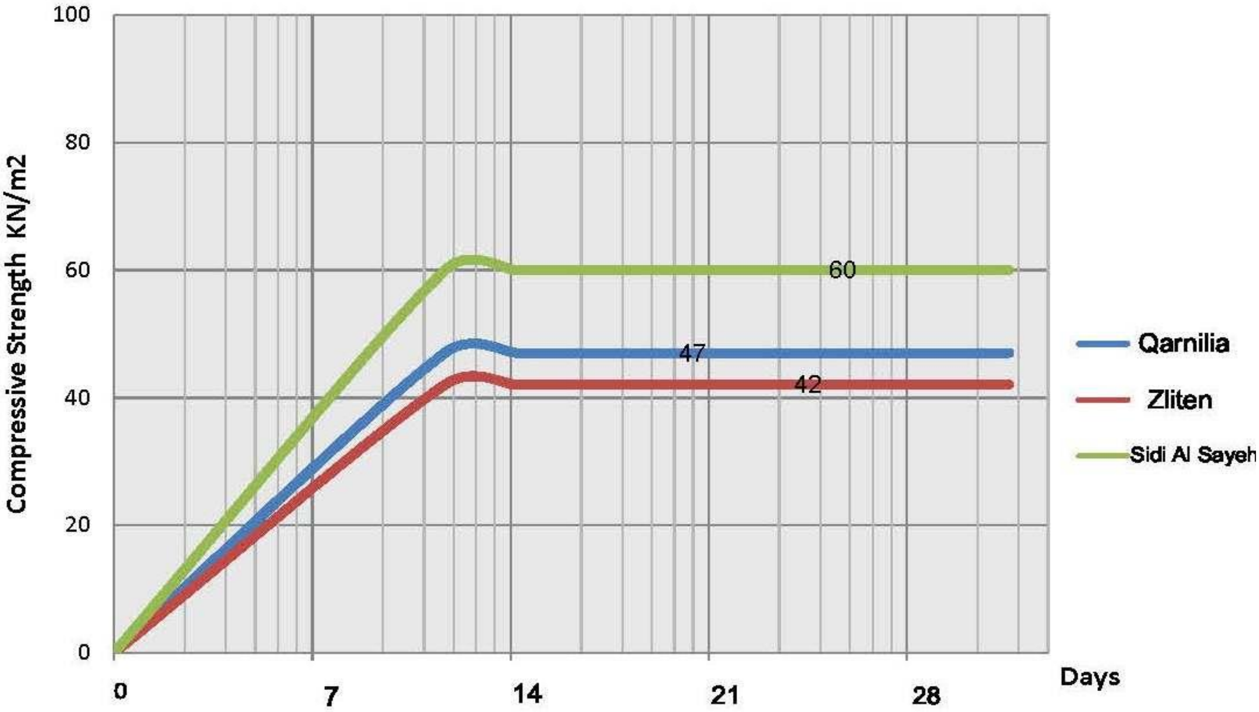

Fig (2) 12% Rubber (14days) Compressive Strength

The compressive strength decreased compared to 9% rubber content, indicating the influence of increasing rubber ratio on concrete strength

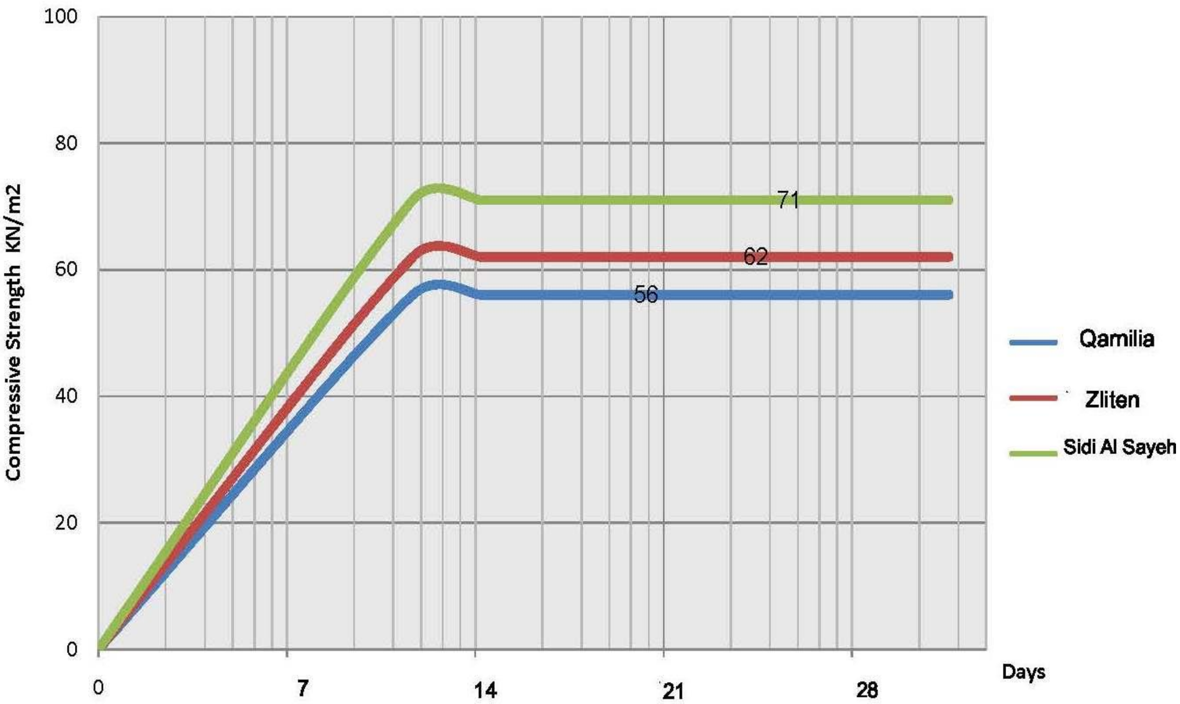

Fig (3) 15% Rubber (28days) Compressive Strength

The results show partial recovery in strength at 28 days due to continued cement hydration and improved microstructure

Discussion

The results clearly indicate that compressive strength is influenced by rubber content, sand type, and curing age. Sidi Al-Sayeh sand consistently showed the highest performance due to better grading and stronger bonding with cement paste. Increasing rubber content generally reduces compressive strength because rubber particles are less stiff than natural aggregates and create weak bonding zones. However, rubber improves ductility and energy absorption, making rubberized concrete suitable for non-critical structural applications.

4. Conclusion

• Rubber particles reduce compressive strength but improve ductility.
• Sidi Al-Sayeh sand has the highest strength results.
• 28-day curing improves strength significantly.
• Rubberized concrete is suitable for sustainable construction applications.

The present study investigated the effect of recycled rubber particles on the compressive strength of reinforced concrete beams using different rubber replacement ratios (9%, 12%, and 15%) and different sand sources (Qarnilia, Sidi Al-Sayeh, and Zliten). Based on experimental results and analysis, several important conclusions can be drawn.

4.1 Influence of Rubber Content on Compressive Strength

The incorporation of recycled rubber particles into concrete significantly affects its mechanical performance, particularly compressive strength. The experimental results of this study indicate that increasing rubber content leads to variations in strength depending on curing age and aggregate type.

At 9% rubber content, the compressive strength reached relatively high values, especially with Sidi Al-Sayeh sand (72 MPa). This indicates that low rubber content can still maintain good load-bearing capacity while introducing sustainability benefits.

At 12% rubber content, a noticeable reduction in compressive strength was observed across all sand types. This reduction is attributed to the weak bonding between rubber particles and cement paste, as rubber is hydrophobic and does not chemically bond with hydrated cement products.

At 15% rubber content, the compressive strength showed mixed behavior, where some recovery in strength was observed at 28 days. This can be explained by continued hydration of cement and densification of the microstructure over time.

4.2 Effect of Sand Type on Concrete Performance

The results clearly indicate that sand type plays a major role in determining compressive strength. Sidi Al-Sayeh sand consistently achieved the highest compressive strength values in all mixtures. This superior performance can be attributed to:

• Better particles distribution (grading)
• Improved packing density
• Stronger in trifacial transition zone (ITZ) with cement paste

in contrast, Qarnilia and Zliten sands showed lower performance, which may be due to less optimal grading or higher void content.

This confirms that aggregate characteristics are as important as rubber content in determining concrete strength.

4.3 Microstructural Behavior of Rubberized Concrete

From a microstructural perspective, the incorporation of rubber particles introduces discontinuities within the cement matrix. These discontinuities act as weak zones where stress concentration occurs during loading.

Rubber particles are also significantly more flexible than mineral aggregates, resulting in:

• Reduced stiffens concrete

• Increased d s of formability
• Higher energy absorption capacity
Although these effects reduce compressive strength, they improve toughness and crack resistance, making rubberized concrete suitable for applications where ductility is required.

4.4 Curing Age Effect

Curing age has a significant influence on the compressive strength of rubberized concrete.

- At an early age (7 days), strength development is mainly controlled by initial hydration.
- At 14 days, hydration continues and strength increases moderately
- At 28 days, the cement matrix becomes denser and stronger due to full hydration.
  The results show that longer curing periods partially compensate for strength loss caused by rubber particles.

4.5 Comparison with Previous Studies

The results of this study are consistent with recent research findings (2023–2024), which indicate that:
• Rubber content above 10% generally reduces compressive strength
• Rubber improves ductility and energy absorption
• The interfacial bond between rubber and cement is the main factor affecting strength reduction.
Several researchers have reported similar trends, confirming that rubberized concrete is more suitable for non-critical structural elements such as pavements, barriers, and vibration-resistant structures.

4.6 Engineering Implications

From an engineering point of view, the results suggest that rubberized concrete should be designed carefully depending on its intended application. Suitable for:
• Pavements
• Sidewalks
• Lightweight structural elements
• High-load structural beams
Not recommended for:
• Impact-resistant structures Not recommended for:
• Columns requiring high compressive strength
However, its environmental benefits make it an attractive material for sustainable construction practices Advanced Additions: Enhanced Scientific Aspects.

5. Recommendations

• User rubber content below 10% for structural elements.
• Improve ending between rubber and cement paste.
• Further studies should include tensile and flexural strength.
• Evaluate durability under environmental conditions. Advanced Discussion (Strong Section)

5.1 Main Findings

The incorporation of rubber particles into concrete significantly influences its mechanical behavior. The results clearly demonstrate that compressive strength is affected by rubber content, sand type, and curing age.

Sidi Al-Sayeh sand consistently produced the highest compressive strength values, reaching up to 72 MPa, which indicates superior particle grading and better bonding characteristics compared to other sand types.

On the other hand, Zliten sand showed relatively lower performance, confirming that aggregate quality plays a crucial role in determining concrete strength.

5.2 Effect of Rubber Content

The study confirms that increasing rubber content generally leads to a reduction in compressive strength due to the weak interfacial bonding between rubber particles and cement paste. Rubber particles are flexible and hydrophobic, which results in:

- Increased micro-void formation
- Reduced stiffness s of concrete
- Lower load transfer efficiency

However, this reduction in strength is not necessarily a disadvantage in all cases.

5.3 Structural and Engineering Insight

Although compressive strength decreases with higher rubber content, the material exhibits significantly improved ductility and energy absorption capacity. This behavior is particularly important in:

- Earthquake- structures
- Impact- resistates elements
- Vibration damping systems

This indicates that rubberized concrete should not be evaluated only by strength, but also by its energy dissipation and deformation capacity, which are critical in modern structural design.

5.4 Sustainability Impact

From an environmental perspective, the use of recycled rubber in concrete provides a strong contribution to sustainable construction. It helps in:

- Reducing waste tire accumulation
- Lowering environmental pollution
- Promoting circular economy principles
- Reducing dependency on natural aggregates

This makes rubberized concrete an environmentally friendly alternative material.

5.5 Final Engineering Conclusion

In conclusion, rubberized concrete presents a trade-off between strength and sustainability. While compressive strength is reduced with increasing rubber content, the material gains significant advantages in ductility, toughness, and environmental performance.

Therefore, rubberized concrete can be considered suitable for:

- Non- structure elements
- Lightweight structural components
- Infrastructure requiring energy absorption

However, careful mix design is required when applying it in load-bearing structures.

Final Statement

This study demonstrates that waste tire rubber, once considered an environmental burden, can be transformed into a valuable construction material. With proper proportioning and material selection, rubberized concrete can contribute to the development of safer, more sustainable, and more resilient infrastructure systems. Limitations of the Study Although this study provides valuable insights into the effect of recycled rubber particles on the compressive strength of reinforced concrete beams, several limitations should be acknowledged to ensure a balanced and realistic interpretation of the results.

6.1 Limited Rubber Replacement Range

The study was conducted using only three rubber replacement ratios (9%, 12%, and 15%). While these values provide a good indication of performance trends, a wider range (e.g., 0%–20%) could give a more comprehensive understanding of the optimal rubber content.

6.2 Limited Mechanical Properties Investigated

The research focused primarily on compressive strength. However, other important mechanical properties such as:

- Tensile strength

• Flexural strength
• Modulus of elasticity
• Impact resistances were not experimentally investigated.

These properties are essential for fully evaluating the structural behavior of rubberized concrete.

6.3 Aggregate and Material Variability

Only three types of sand (Qarnilia, Sidi Al Sayeh, and Zliten) were used in this study. The results may vary in different aggregate sources, or different grading distributions are used. Therefore, the findings may not be universally applicable to all material conditions.

6.4 Lack of Microstructural and Chemical Analysis

The study did not include advanced microstructural analysis techniques such as:

• Scanning Electron Microscopy (SEM)
• X-ray Diffraction (XRD)
• Chemical bonding analysis These methods could provide deeper understanding of the interfacial transition zone (ITZ) between rubber particles and cement paste.

6.5 Environmental and Durability Testing Constraints

Although the study highlights the sustainability benefits of rubberized concrete, long-term durability tests such as:

• Freeze– thaw resistance
• Chloride penetration
• Carbonation depth

We're not performed, which limits the assessment of long-term performance.

6.6 Scale of Experimental Work

The experimental work was conducted at laboratory scale. Therefore, real field conditions such as environmental exposure, loading variations, and construction practices were not fully simulated.

Final Note

Despite these limitations, the study still provides strong experimental evidence and contributes valuable findings regarding the behavior of rubberized concrete. Future research is recommended to address these limitations and expand the understanding of this sustainable material

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