Compressive and Flexural Tensile Strength Impacts of Aluminum Shavings in Concrete

Ian Smith
California Polytechnic State University,
San Luis Obispo, California

Concrete is one of the most utilized construction materials around the world, but new and cutting-edge methods are constantly pushing the envelope for concrete’s applications and feasibility as a construction material. Unfortunately, concrete has a general lack of resistance to bending and stretching. Studies have shown several successful attempts to enhance the mechanical properties of concrete through implementation of various admixtures and methods. Steel is widely considered the primary material capable of reinforcing concrete. This paper evaluates concrete’s change in strength of flexural tension and compression as a result of implementing aluminum as a reinforcing agent. To determine the full potential of aluminum in concrete, it is tested concurrently as well as isolated from rebar. The study demonstrates an increase in compressive strength by 33.7%, with minor quantities of aluminum shavings. The strength of flexural tension post failure of the concrete beam increased by 153%. Implementation of minor aluminum quantities proved beneficial. It should be acknowledged that further tests using increased aluminum quantities produced negative results. The workability and consolidation of concrete were also impacted by introducing aluminum into the mix. Materials with similar characteristics to aluminum have potential for increasing the compressive and flexural tensile strength of concrete.

Key Words: Concrete, Aluminum, Flexural Tension, Compression, Strength

Introduction

Concrete is a remarkable building material that has proven itself to maintain substantial versatility in the construction industry. It’s commonly known that concrete is unfathomably strong, but it’s also brittle, meaning it fractures without much deformation occurring beforehand (Wu, Que, & Lambert, 2019). Fractures such as this are commonly a result of tension (stretching) and bending stresses which can result in lost time, productivity or even create an unsafe work environment. To combat concrete fracturing, steel also called rebar, is used as a reinforcing agent that can dramatically decrease brittle behavior. Reinforcing steel has ductile and elastic behavior, which allows deformation of materials
due to stresses, without compromising structural integrity. Unfortunately, steel is a heavy material that isn’t easy to work with. Designing rebar configurations for structural concrete and forming them in the field increases construction time as well as expenses. In addition, setting rebar is one of the most physically demanding trades in construction. In recent years, there have been significant strides in the studies of steel replacements and supplements (Al-Mwanes, Oudah, & Aghayari, 2020). While some of these materials have shown exceptional results, steel is still considered to be the most efficient product for improving the ductility and tensile strength of concrete. Alternative reinforcing materials could greatly decrease costs and construction duration for concrete scopes, but none have produced results comparable to steel.

This study provides results and analysis of strength testing for three separate concrete mixes, two of which contain differing quantities of aluminum shavings while the third contains no aluminum. The tests for this laboratory were administered at California Polytechnic State University, in San Luis Obispo. ASTM and OSHA standards were followed during the construction and testing of nine concrete structures. The primary purpose of this study is to ascertain whether the use of aluminum shavings as an admixture may have beneficial impacts on the flexural tensile and compression strength of concrete.

**Literature Review**

**Increased Strength Concrete**

Concrete has many desirable qualities, such as its ability to carry extreme weight, and withstand intense heat such as flames. Arguably, the most notable characteristics are its natural compressive strength and impressive resistance to weathering. While conducting research on properties of concrete, a scholarly journal, “Physical Properties of Concrete Containing Graphene Oxide Nanosheets” was found (Wu, Que, & Lambert, 2019). The study tested the physical properties of cured concrete that were affected by an implementation of graphene oxide nanosheets within concrete mixes. While concrete is extremely hard, and can withstand substantial pressure, it has poor ductility, thus, minimal tensile and flexural strength without assistance from rebar (Wu, Que, & Lambert, 2019). Flexural and tensile strength are often viewed as the same but flexural strength refers to a material’s ability to withstand bending stresses while tensile strength refers to the ability to withstand tension. The study focused on the idea of utilizing nanotechnology to increase overall strength, resulting in boosted tensile, flexural and compressive strength. The data from the graphene oxide study shows that graphene oxide nanosheets can increase compressive strength yield of cement paste by 34%. Additionally, the tensile strength of cement paste has the ability to increase by 14.9% (Wu, Que, & Lambert, 2019). While remarkable data was gathered, the study suggests a decrease in workability exists. Workability refers to the ease of concrete finishing, and decreased workability insinuates a difficulty to efficiently place and finish concrete. Most of the evaluation was focused on specific products, such as cement paste and mortar, while comparing past research on ultra-high strength concrete and ultra-high-performance concrete. The lack of adequate exposure and data demands further research to better understand the capabilities of concrete containing graphene oxide, but promising strides have been taken.

There are some strength seeking materials that have been used in concrete for decades. One of these materials is fly ash. The scholarly study, “Microsilica and steel dust as nano- and micro-particles addition for increasing the mechanical strength of fly ash and blast furnace slag-geopolymer concrete” explains how fly ash is one of the most consistently used material for geopolymer concrete and is generally accepted to enhance both strength and durability (Păunescu & Volceanov, 2023). Fly ash,
along with other industrial by-products can even be used as a binding agent in concrete, which could theoretically reduce the demand for Portland cement. This process of creating geopolymer concrete uses materials such as fly ash, “dissolved in alkaline activating aqueous solution that facilitates the geopolymerization reaction forming molecular chains with the role of binder” (Păunescu & Volceanov, 2023). When using a replacement binder, cement is not required. Tests were conducted, using 4 separate batches of geopolymers on concrete, with increasing rates of geopolymers, to assess the changes in compressive and flexural strength. Results of the study demonstrated an ability to increase the compressive and flexural strength of the geopolymer concrete through use of larger quantities of fly ash, steel dust, and nano silica. The change in compressive strength, and flexural strength from sample 1 to 4 is 71.7% and 36% respectively (Păunescu & Volceanov, 2023). Simply altering the ratios of materials for geopolymer concrete can greatly impact overall strength. It is important to note that while the results are noteworthy, no direct comparison can be made to standard structural concrete from gained data. The geopolymer acts as a binding agent in place of cement, and the study didn’t include a control mix using cement, which would help draw reasonable correlations. Further research could prove to substantiate the original data and help lead to standardizing higher strength and durability concrete.

Another widely accepted method of improving concrete strength is through the application of reinforcing fibers within the mix design. Verification of this notion is found within “Study of the effect adding the polypropylene fibers and chemical additives on the behavior of Ultra-High-Performance Concrete” (Al-Mwanes, Oudah, & Aghayari, 2020). Through examination of utilizing increased quantities of polypropylene fibers, the tests prove enhanced mechanical strength, including compression and tension. There are several types of synthetic fibers which are known to supplement strength, including glass, polypropylene, and steel fibers. Polypropylene fibers were chosen for the investigation. It should be noted that ultra-high-performance concrete (UHPC) was used, and shouldn’t be directly compared to standard concrete. Ultra-high-performance concrete has larger than standard quantities of cement (binding agent), which allows for decreased thickness requirements, and substantial material weight reduction (Al-Mwanes, Oudah, & Aghayari, 2020). The examination of impacts that polypropylene fibers may have on UPHC included 8 samples with varying levels of superplasticizer and polypropylene fibers. To most accurately assess the results of reinforcing concrete with fibers, data should only be taken from mixes with consistent quantities of superplasticizer. By comparison of mix 1, with 0% fiber versus mix 4, with fiber consisting of 1.5% of total concrete weight, the gain in strength of compression was found to be 10.6%. The gain in strength of tension was found to be 14.9% (Al-Mwanes, Oudah, & Aghayari, 2020). It is evident that the use of reinforcing fiber as an admixture in concrete can result in improved mechanical properties and could be influential to the development of high tensile strength concrete.

**Hypothesis**

There are many materials that have been used to reinforce concrete, however, none that would satisfy the tensile strength requirements of typical concrete without the concurrent use of steel. To further research on materials that can provide benefits to the compressive and tensile strength of concrete, this study focuses on introducing aluminum, specifically aluminum shavings to concrete mix designs. Aluminum is a highly plentiful and affordable material, especially in comparison to steel (Toward, 2020). In addition, aluminum has ductile behavior, similar to steel, which could help to reduce concrete’s natural tendency to shear from forces other than compression. Inherently, soft materials are ductile, and strong materials are brittle, but there are possibilities to create products with a balance of brittle and ductile behavior (Toward, 2020). Due to aluminum’s natural ability to deform under stress without compromising structural integrity, it may reduce the negative characteristics of concrete. In
addition to supporting evidence that implementation of synthetic fibers, graphene oxide nanosheets, and geopolymers produce strengthened mechanical attributes, there is reason to believe aluminum shavings could display similar beneficial results. This study investigates the change in the compressive and flexural tensile strength of concrete, through application of increasing proportions of aluminum shavings.

Methods

Three separate batches of concrete were created. To produce accurate data for compression and tension, each batch of concrete was used for both tests. For concrete compression tests, a pre-manufactured test cylinder, measuring 12” in height and 6” in diameter must be filled and cured before testing. Tensile strength testing requires wood formwork to be assembled, for the curing of 4” wide, 4” tall, and 30” length concrete beams. Formwork was built using 5/8” plywood, and wood screws. Six forms were built for tensile strength testing, using each batch of concrete in a form with rebar and one without. The construction of all concrete structures occurred in the Construction Materials Laboratory at California Polytechnic State University, using the school’s concrete mixer. The coarse aggregate used for this study is 3/8” pea gravel, obtained locally at the Cal Portland quarry in San Luis Obispo. The binding agent used is Cal Portland type II cement. Aluminum was obtained from recycling facilities, amounting to six hundred grams total. Each material was weighed on a scale that is accurate to the nearest 0.1 pound/gram, and kept separated until the start of the mixing process. The materials were poured into the concrete mixer in the following sequence: coarse aggregate, fine aggregate, cement, and finally water. One batch was used as a control sample, without the application of aluminum shavings but two batches required aluminum. For the two batches containing aluminum, the shavings were slowly added after the mixture of water to ensure aluminum quantities were consistent throughout the entire batch. The precise material quantities of each batch can be found in table 1.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Coarse Aggregate (lbs)</th>
<th>Fine Aggregate (lbs)</th>
<th>Cement (lbs)</th>
<th>Water (lbs)</th>
<th>Aluminum (grams)</th>
<th>Slump (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Control)</td>
<td>67.5</td>
<td>52.5</td>
<td>30</td>
<td>15</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>67.5</td>
<td>52.5</td>
<td>30</td>
<td>15</td>
<td>200</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>67.5</td>
<td>52.5</td>
<td>30</td>
<td>15</td>
<td>400</td>
<td>0.5</td>
</tr>
</tbody>
</table>

After a thorough mixture of concrete ingredients, the sample was emptied into a wheelbarrow and relocated to the designated pouring location of the lab. A portion of the sample must be taken for the purpose of conducting a slump test, results shown in table 1. The slump test chosen was ASTM C143, standard test method for the slump of concrete, with a test cone that measures 12” in height, 4” in top diameter, and 8” in bottom diameter (ASTM, 2015). The slump test cone is first filled 1/3 of the way
and is compacted 25 times with a rod in circular motion. Concrete was added and compacted in the same manner two more times, ensuring the concrete was level with the top of the cone. The cone must be carefully removed and flipped upside down. Height difference between the 12” cone and the compacted, uncured concrete is the slump (ASTM, 2015). The same process was necessary for creating a concrete cylinder, filling the pre-manufactured hollow cylinder with 3 layers of concrete, and compacting each layer in circular motions with a metal rod. The process for developing concrete cylinder samples complies with ASTM C31, Making and Curing Concrete Test Specimens in the Field (ASTM, 2019). Another portion of each batch of concrete was placed into 2 rectangular, wood forms. One piece of #3 rebar at a length of 26” was installed in the lower ⅓ of half of the rectangular forms, to allow for optimum comparison. Aluminum shavings seemed to reduce workability and consolidation of the material, requiring 5 layers of concrete to be compacted using an immersion vibrator at each layer. The final product was screeded to level height with wood formwork. Creating multiple forms for each batch allows for testing of the concrete with aluminum alone, as well as aluminum and rebar used concurrently. The process of slump test, cylinder curing, and beam curing was repeated twice for the other two batches of concrete, resulting in a total of 9 concrete specimens. Only the weight of aluminum in each batch was altered, material quantities for fine aggregate, coarse aggregate, cement, and water remained consistent within all 3 batches.

**Instruments and Testing**

Multiple instruments of testing are needed to obtain both flexural tension and compression tests, because of the differing nature of required forces. Tests were conducted on 9 separate concrete structures, after 28 days of curing to allow for maximum strength yield. Concrete typically reaches 99% of its strength within 28 days. The instrument used for assessment of compressive strength is a hydraulic press, with a cage entrapping the device to prevent injury in the case of highly destructive concrete. The device is shown in figure 1. The instrument used to obtain flexural tensile strength is a Universal Testing Device that was configured to produce desired test and is shown in figure 1.

![Figure 1. Compression and Flexural Tension Testing Equipment](image)

**Results and Data**
The integration of aluminum in the concrete mix design displayed signs of decreased workability and consolidation, before and after the concrete cured. The cured concrete samples are shown in figures 2 and 3. The utilization of aluminum immediately impacted the ability to place concrete, as the material became resistant to flow. Workability is an important aspect of concrete pours in the field, as it can alter the number of laborers needed, the tools for finishing, as well as the time spacing needed between concrete trucks. Consolidation refers to the ability for the materials in the mix to evenly spread, which produces higher strength and weather resistant concrete. The consolidation greatly decreased when aluminum was introduced to the mix design and required significant vibration to properly consolidate. The finish of the concrete was also affected due to consolidation, and aggregate became visible on every beam and cylinder that contained aluminum.

![Figure 2. Cured concrete specimens for compression testing](image)

Compressive strength testing produced both positive and negative results. The mixes and their respective compression strength are shown in figure 4. Mix 1 operated as the control mix, without aluminum, while mix 2 contained the same materials, with 200 grams of aluminum. Mix 3 contained the same original materials, with 400 grams of aluminum in the mix design. In comparison to the control mix, mix 2 displayed an increased compressive strength of 33.7%. Unfortunately, there was a
dramatic decline in strength with the addition of 400 grams of aluminum. In comparison to the control mix, mix 3 displayed a decreased compressive strength of 55%.

![Mix Strength](image)

**Figure 4.** Graph of compression strength test results

The flexural tensile strength test portrayed the same pattern of strength changes due to the implementation of aluminum. Mix 2 resulted in an increase of 153% to the flexural tensile strength of the concrete, when compared to the control mix. Again, the use of larger quantities of aluminum (400 grams) in mix 3 proved detrimental. The flexural tensile strength decreased by 66%. The results are graphed in figure 5. It should be noted that the graph in figure 5 reflects the load that the concrete beams were able to carry after failure. Each of the beams graphed failed at 5000 PSI. Many patterns stayed consistent throughout the tests conducted. The workability and consolidation decreased each time more aluminum was added to the mix, but the strength was improved from minor quantities of aluminum. Each test resulted in significant strength gains for mix 2 but there were diminishing returns as mix 3 proved weaker in compression and flexural tension.

![Load Carried After Break](image)

**Figure 5.** Graph of flexural tension strength test result
Conclusion

The data collected throughout the study indicates that further testing should be conducted to obtain conclusive evidence that aluminum can improve the design strength of a concrete mix. While the results were consistent, they aren’t substantive enough to support aluminum as a positive reinforcement agent within concrete. The study suggests that aluminum has characteristics that can enhance the strength of compression and flexural tension. There are, however, many factors to consider before aluminum could be implemented into everyday mix designs. It is evident that the strength advantages of aluminum have diminishing returns, thus, a specific ratio of aluminum shavings would produce optimum strength benefits.

Due to a lack of time and resources, this study doesn’t provide enough data to determine the optimum aluminum ratio. To adequately determine the potential of aluminum shavings within concrete, several more batches would be needed, with varying ratios of aluminum. In addition, the strength should be analyzed after longer curing durations. The strength at 5 years may be different from the 28 day strength, which is an important variable to consider. The lack of workability and consolidation when implementing aluminum shavings should also be considered, as these necessary qualities for efficient concrete placement. Tests should be conducted using smaller shavings, potentially even powder. The large volume that the aluminum filled seemed to be the reason for limited consolidation and workability. Products for assisting these faults are readily available and widely used.

The integration of alternative reinforcing materials has been studied for decades, but steel has not been replaced as the primary reinforcement. While graphene oxide nanosheets, geopolymers, reinforcing fibers, and even aluminum have shown improvements to the mechanical properties of concrete, rebar will always outperform significantly. The concurrent utilization of multiple reinforcing materials may produce significant results and improve the inherent characteristics of concrete. This study displayed a remarkable increase in concrete’s flexural tension and compression strength but doesn’t provide the data needed to prove that aluminum shavings are a beneficial admixture within concrete mix designs.
References


