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Substitution of Recycled Plastic Aggregates (RPA) in concrete and its influence on pullout capacity of mechanical and chemical anchors

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SUBSTITUTION OF RECYCLED PLASTIC AGGREGATES (RPA) IN CONCRETE AND ITS INFLUENCE ON PULLOUT CAPACITY OF MECHANICAL AND CHEMICAL ANCHORS

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ABSTRACT: There is a lot of plastic going to land fill or entering environmentally sensitive systems, that could ideally be converted into a form or material that would be considered as a resource. Much of this plastic waste is not suitable for re-cycling or use, where exposed to sun light or weathering elements. Some of these materials have been converted to granular materials and used in sub-soil drainage systems as free draining materials and as substitute for aggregates in concrete pavements. There is significant enthusiasm for utilising 'environmentally friendly' construction systems and materials. Unfortunately, that enthusiasm can result in them being utilised in in-appropriate situations that can have a negative result to the reputation of the material or system. The aim of this project was to determine if anchors and fixings inserted into Recycled Plastic Aggregates (RPA) concrete elements will perform as expected and required. Proprietary RPAs were procured from a commercial supplier to substitute for natural concrete aggregates in various proportions. Normal and RPA concrete cylindrical samples were manufactured in a controlled environment at USQ lab and subsequently cured for 28 days. The purpose of manufacturing and testing normal concrete samples, involving standard concrete blends, was to provide a reference point when comparing the performance of the RPA concrete systems. Compression tests were performed on both normal and RPA concrete samples using the universal load test machine. On the other larger samples, holes were drilled in the normal and RPA concrete samples to install proprietary mechanical and chemical anchors so pull-out tests could be performed to simulate real life scenario. These pull-out tests were also performed on universal load test machine. The 50% RPA concrete demonstrated significant capacity reduction and to the extent that these rates cannot be sustainable. The 20% RPA concrete has demonstrated reduction in capacities that could conceivably be tolerated in the construction industries. The mechanical anchors were noticeably more affected by the RPA substitution than the chemical anchors. The substitution of recycled plastic provides a sustainable option for offsetting waste plastic going to landfill, thereby reducing environmental pollution. This study develops confidence in the performance of post fixed anchors inserted into low percentage RPA concrete, creates awareness in the industry and supports recycling through buying products which include recycled content in line with Australian Government National Plastic Plan 2021.

INTRODUCTION

Plastic has many valuable uses and has become an essential part of our lives. Humans are mostly using plastic products for single use, and these are disposed of subsequently, resulting in severe environmental implications. Millions of plastic bottles and bags worldwide are of single use and majority of these products are designed to be used only once and are subsequently disposed. Therefore, plastics are rapidly growing segment of the municipal solid waste. Plastics are found in non-durable products such as bags, cups, utensils, medical devices and a variety of household items. The plastic food service items are generally made of clear plastic or foamed polystyrene, while trash bags are made of high-density polyethylene (HDPE) or low-density polyethylene (LDPE). Most of the countries in the world are concerned that plastic pollution has become one of the most pressing environmental issues, as rapidly increasing production of disposable plastic products overwhelms the world's ability to deal with them. Although, plastic pollution is most visible in developing nations, where the garbage collection systems are often inefficient or non-existent, the low recycling rates in the developed world are also suffering when it comes to collection and management of used plastics. In the recent years we have seen some great initiatives taken by governments and organizations in the management and reuse of recycled

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plastics such as use in concrete and thereby reducing the footprint in the landfill. This research has provided an opportunity to investigate one avenue of substituting plastics as aggregates in concrete and exploring the behaviors and characteristics when the system is used as a base material for mechanical and chemical anchors. This research aims to ensure that these anchors set into Recycled Plastic Aggregates (RPA) concrete elements will perform as expected and required.

The utilisation of recycled plastic in concrete, as a partial or full replacement of natural aggregates, was investigated by Shaik InayathBasha, M.R.Ali, S.U.Al-Dulaijan and M.Maslehuddin (1994). They tested various concrete samples with varying proportions of RPA. The study showed that whilst the unit weight of RPA concrete had significantly reduced by the quantity of RPA, there was no significant effect on cement content, water-cement ratio and shape of RPA. However, the compressive and flexural strengths, modulus of elasticity, and bond strength had decreased with an increase in the quantity of RPA. As a result, the RPA concrete is recommended to be used as a light weight and low strength material only. Whilst another study by Baboo Rai, S. Tabin Rushad, Bhavesh Kr, and S. K. Duggal (2012) has also shown similar observations on the characteristics of RPA concrete, it was also studied that the use of superplasticizer can enhance the workability and compressive strength of the RPA concrete. Although, the concrete mixes (with reduced slump values) may be used only in applications that required low-degree workability such as precast bricks, partition wall panels, canal linings etc. The research showed the workability had increased by about 10 to 15% when superplasticizer was added to the RPA concrete. Similarly, the compressive strength had also increased by about 5% after the addition of superplasticizer to the mix. With increasing amount of RPA, the rate of reduction in strength gets flatter and the maximum reduction is only about 15% for all grades of concrete. Flexural strength of the RPA concrete had decreased with the increase in percentage of RPA. Therefore, it was observed that the effect of plasticizer on flexural strength of concrete is irrelevant. One common aspect (of both the aforementioned studies) was that the flexural strength of concrete was affected by substituting RPA, regardless of introducing plasticizer. A study by Dora Foti (2012) investigated how the polyethylene terephthalate (PET) fibres can help improve the tensile strength of concrete. Test results from several concrete samples, including fibres and long strips from plastic bottles, had indicated more ductile behavior of concrete and a high concrete-PET adherence. Study therefore suggests a possible use of this material in the form of flat or round bars or networks for structural reinforcement. These studies have concentrated on the material structural properties and have not assessed how the change in these properties will affect the bond characteristics to reinforcement, cast-in elements and other post-fixed anchors or fixings. Whilst there is significant enthusiasm for utilising ‘environmentally friendly’ RPA concrete, there’s a risk this enthusiasm may result in the material being utilised in in-appropriate situations that can have a negative result to the reputation of the material or system. One of the biggest risks to structural failure or underperformance is associated with the bond of these materials to reinforcement, structural cast-in elements and post-fixed anchors or fixings. This research at USQ aims to investigate the characteristics and behavior of RPA concrete when used as a host material for chemical and mechanical anchors. There is a lot of research into plastic aggregate or plastic fiber substitute of the sands or fine aggregates or coarse aggregates and the effects on density, workability and other mix characteristics. There appears to be plenty of opportunity to research the more structurally useful characteristics of blends of both plastic aggregates and plastic fibers substituting some sands and some fine aggregates and some coarse aggregates. Whilst this study doesn’t form part of this research, we anticipate that better concrete will produce better anchorage capabilities and therefore, there is an opportunity for a future project to investigate this further. Another important aspect of the RPA concrete system worth exploring are the options when the product reaches its end of life. Whilst this study doesn’t form part of this research, there is an opportunity for a future project to investigate this further.

SAMPLE PREPARATION AND EXPERIMENTAL SETUP

An essential component of this research is the undertaking of sufficient practical work to enable well founded assessment and support the conclusions & recommendations. The scope for this practical work involved the preparation and testing of three samples of each test item in a controlled environment provided by the USQ civil engineering labs, being the Z1 lab for material manufacturing and the P11 lab for compressive and pull-out strength testing under the supervision of qualified technicians. Procuring test materials from a reputable manufacturer and supplier, instead of producing our own, ensured consistency and access to a significant amount of reference materials. For this study, the anchors and adhesives were procured from Ramset and the plastic aggregate for the proposed base material (RPA concrete) was procured from REPLAS (www.replas.com.au). REPLAS appreciated our initiative and supported this research work by supplying 15kg of Polyrok for the experimentation purposes. We also procured the other raw materials for this industry project such as cement, sand and gravel from the same source as the USQ lab. This was not only done in order to avoid the potential for contaminating the existing materials or resources of the USQ lab, it also ensured consistency of the materials used to prepare a standard USQ concrete blend and therefore, provided a source of reference data of similar blends, should it be required. Three samples of each test specimen were produced to ensure good representation of the results. Test specimens of normal concrete, 20% RPA concrete and 50% RPA concrete were produced for the following tests:

- Concrete compression testing
- Mechanical Anchor pullout testing
- Chemical anchor pullout testing

The normal concrete samples were produced to provide a reference point to anchor capacities in conventionally produced concrete and provide reference to the manufacturer provided reference material and published anchor capacities. The RPA sampling represents a percentage replacement by volume of the coarse aggregate used in the normal concrete sampling. This method of substitution was adopted because it represented the production methods adopted in the industry for non-structural and landscape concrete works to date. The 20% RPA samples were produced to represent the higher substitution rates that have generally been adopted in the industry for non-structural and landscape concrete works to date. The 50% RPA samples were produced to provide an extrapolation of results for the product with substitution rates that exceeded what is currently considered commercially viable concrete blends. Mechanical anchors and chemical anchors were selected as they are indicative of the two main anchor types utilised in the industry and are readily available in most hardware stores or bolt supply shops. The Ramset products were selected as they are from one of the two main suppliers to the industry and specific anchor types were selected as they are the most commonly utilised anchors by both the commercial industry and the DIY domestic home body builder. The intent of this investigation is to have relevance to as wide an application and audience as possible. We anticipate that it may be the foundation of further and more specific testing for conditions related to more specific applications.

Figure 1: Samples (Comp. Test and Mech. Anchors)

Figure 2: Samples (Chemical Anchors)

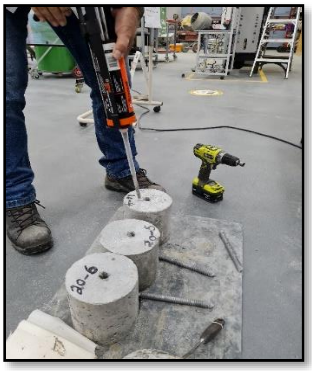

Figure 3: Chemical Anchor Installation

Figure 4: Comp. Test - Normal Concrete

Figure 5: Comp. Test - 20% RPA

Figure 6: Comp. Test - 50% RPA

Figure 7: Samples (Mech. & Chem. Anchors)

Figure 8: Anchor Pullout Test – Universal Load

Figure 9: Anchor Pullout Test Test Machine

RESULTS AND DISCUSSION

Compression Strength Test

The compressive strength tests were performed on normal and RPA concrete cylindrical samples after allowing 28 days of curing. The results of the normal concrete samples therefore act as the reference point when assessing the performance of concrete containing 20% and 50% RPA.

The purpose of this investigation was to determine the influence on anchor capacity. Compression testing of the different concrete sampling was undertaken primarily as confirmation that the different concrete mixes are behaving as predicted and provide confidence in the quality of the samples. These results could also provide some correlation between compressive capacity and anchor capacity where it was apparent that the anchor capacity resulted from failure of the concrete. As predicted, the compression strength of the samples containing RPA reduced in capacity with an increase in the RPA content. The standard concrete sample demonstrated capacities characteristic of a 32MPa mix whereas the 20% RPA sample was more characteristic of a 20 MPa concrete and the 50% RPA sample was more characteristic of a 15 MPa concrete. It was also observed that the characteristics of the failure changed. The sudden brittle failure of the standard concrete sample was not observed in the samples containing RPA which demonstrated a more ductile behavior. Evidence of some local crushing in the RPA concrete samples could be heard and seen prior to the sample reaching its maximum capacity. After the maximum capacity was achieved in the RPA samples, there was no sudden collapse of the sample and no catastrophic reduction in capacity, the sample capacity progressively reduced as it proceeded to deteriorate through localized crushing. Upon removing the fractured wedge post compression test using tools, the plastic aggregates were found intact along the fractured surface and did not disintegrate.

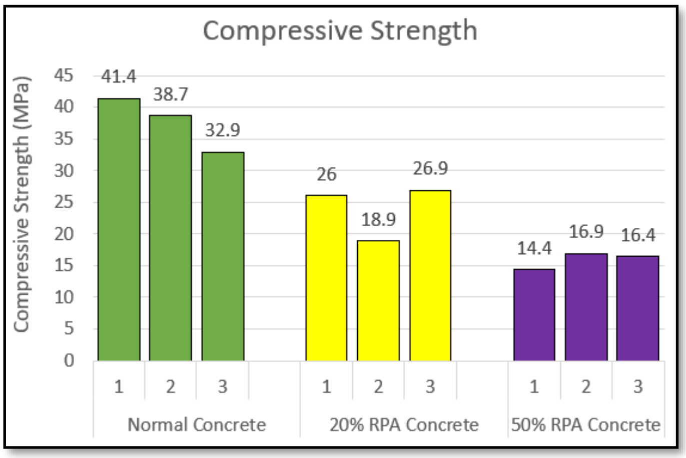

Figure 10: Comparison of Compressive Strengths

Figure 11: RPA Remained Intact Post Failure due to Compression

The slight variation in results shown in **Figure 13** could be due to inconsistent compaction of concrete in sample 3 at the time of pouring or a possible error in the load test machine. The results of sample 1 and 2 are however consistent.

Compression Strength Results

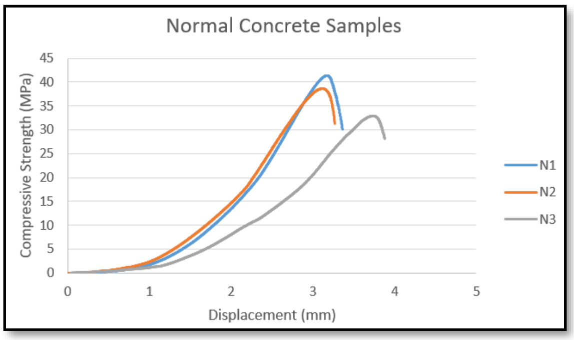

Figure 12 Compressive Strength - Normal Concrete

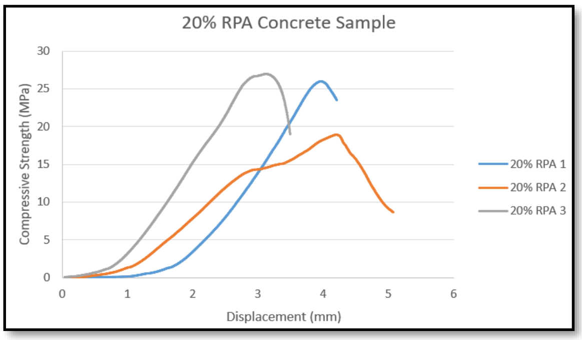

Figure 13 Compressive Strength - 20% RPA Concrete

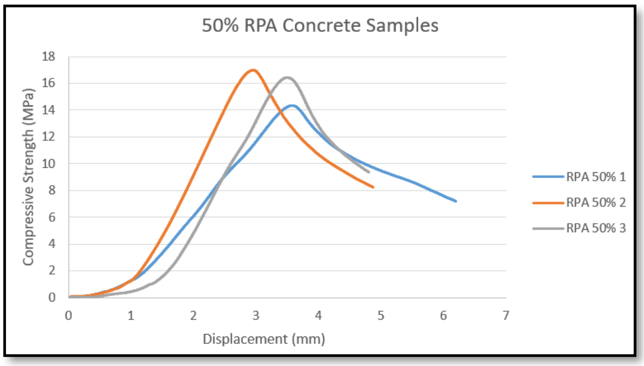

Figure 14 Compressive Strength - 50% RPA Concrete

Pullout Strength Test (Mechanical Anchor)

The mechanical pullout strength tests were performed on normal and RPA concrete cylindrical samples after allowing 28 days of curing. The results of the normal concrete samples therefore act as the reference point when assessing the performance of concrete containing 20% and 50% RPA. There was a notable reduction of capacity with increased RPA. Load exceeded 16kN for the standard concrete samples, exceeded 14kN for the 20% RPA samples and exceeded 9kN for the 50% RPA samples. The experimentation in the USQ P11 lab has shown that all mechanical anchors failed as a result of the anchor pulling out of the drilled hole. All of the concrete samples maintained their integrity throughout the testing with only some minor edge spalling experienced as the test equipment settled into applying the load. The applied load slowly extracted the anchor from the hole. This was as a result of a combination of 2 observed mechanisms, being as a result of exceeding friction capacity between the anchor sleeve and the drilled hole surface; and as a result of the anchor shaft being drawn further into the anchor expanding sleeve. We were not able to identify if one of these mechanisms consistently represented the initial anchor movement, only that both mechanisms appeared to develop during the extraction process. The maximum load generally developed at the initial movement, however there were instances that the maximum load developed part way through the extraction. It appears that the reduced friction capacity is a result of a combination of the friction characteristics of the plastic aggregates and the drill hole surface pitting resulting from the plastic aggregate removal during the drilling process. Further investigation will be required to confirm the observation and determine the relevant contribution of these actions.

Pullout Strength Results (Mechanical Anchors)

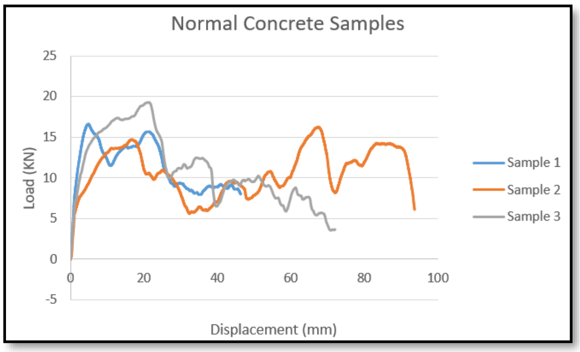

Figure 15: Mech. Anchor Pullout Test Results - Normal Concrete

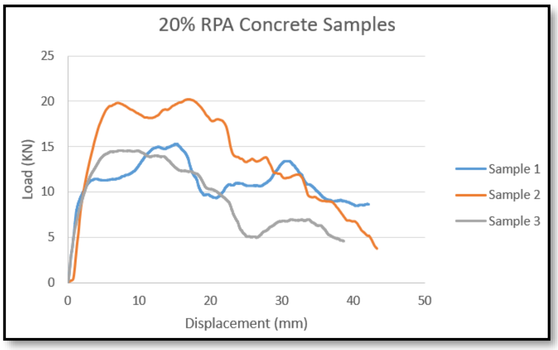

Figure 16: Mech. Anchor Pullout Test Results - 20% RPA Concrete

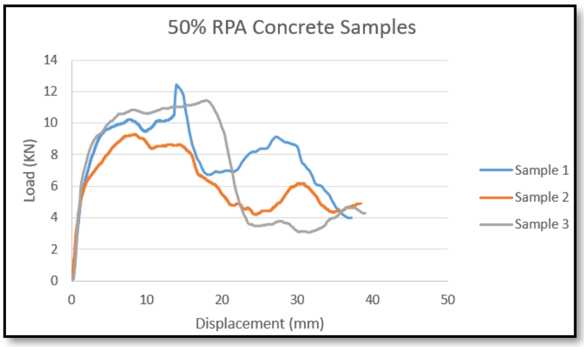

Figure 17: Mech. Anchor Pullout Test Results - 50% RPA Concrete

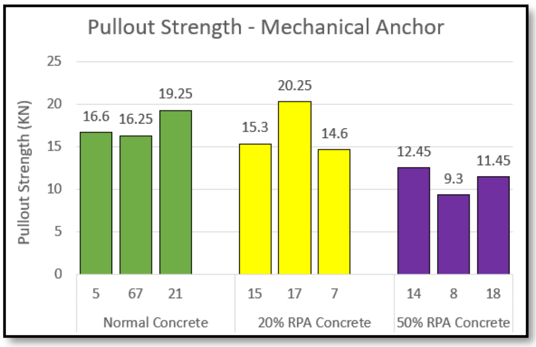

Figure 18: Comparison of Pullout Strengths

Pullout Strength Test (Chemical Anchor)

The chemical anchor pull-out strength tests were performed on normal and RPA concrete cylindrical samples after allowing 28 days of curing. The results of the normal concrete samples therefore act as the reference point when assessing the performance of concrete containing 20% and 50% RPA. The pullout tests on chemical anchors in normal and RPA concrete have concluded that the chemical anchors did not fail. Generally, the maximum load capacity was achieved as a result of either the ductile failure of the threaded rod fixed to the anchors or the failure of the concrete sample. For the normal concrete sample, the maximum capacity was typically governed by threaded rod capacity, however, one sample developed cracking in the concrete prior to the rod failure. On one occasion, the bolt failure occurred in a normal concrete sample when the M16 extension rod snapped into half whilst the anchor and the normal concrete sample remained intact and uncracked. This was because the pull-out load of 67.5kN reached the maximum capacity of the grade 4.6/s M16 bolt. The failure mode in RPA concrete sample was typically achieved upon cracking of concrete at the maximum pullout load. Therefore, the maximum capacity was governed by the failure of the concrete sample. It is to be noted that the concrete failure was typical of the ductile like mechanism that was identified in the compression testing. There was a notable reduction of capacity with increased RPA. Load exceeded 57kN for the standard concrete samples, exceeded 48kN for the 20% RPA samples and exceeded 47kN for the 50% RPA samples. The chemical anchor capacity reduced with the inclusion of RPA primarily as a result of the concrete reduced capacity. The effect on the anchor capacity at the interface between the epoxy and the drilled concrete surface is likely to be improved by the pitting resulting from the plastic aggregates removed as a result of the drilling. It will be necessary to reduce the anchor depth and probably provide confinement reinforcement to the concrete sample in order to encourage failure at the anchor. The chemical anchor capacity reduced with the inclusion of RPA, primarily as a result of the concrete reduced capacity. The increased proportion of RPA in concrete resulted in more ductile behavior, as can be seen in the graph **Figure 21**.

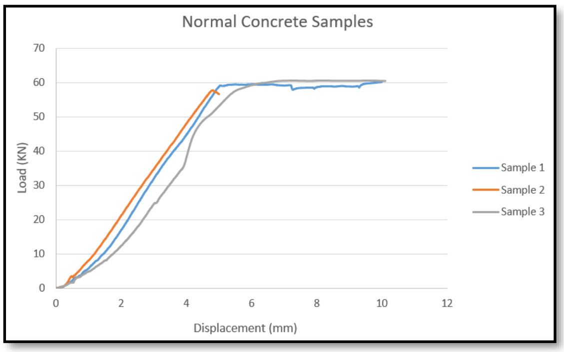

Figure 19: Chem. Anchor Pullout Test Results - Normal Concrete

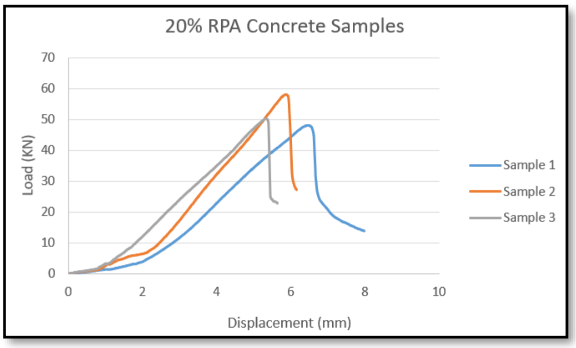

Figure 20: Chem. Anchor Pullout Results - 20% RPA Concrete

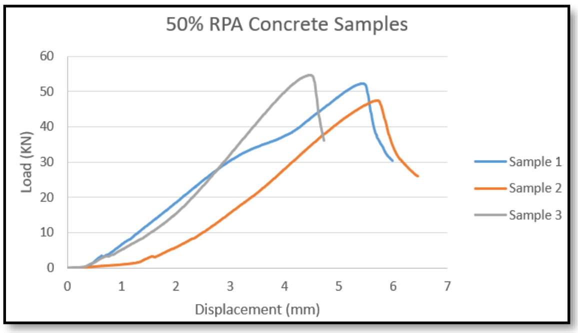

Figure 21: Chem. Anchor Pullout Results - 50% RPA Concrete

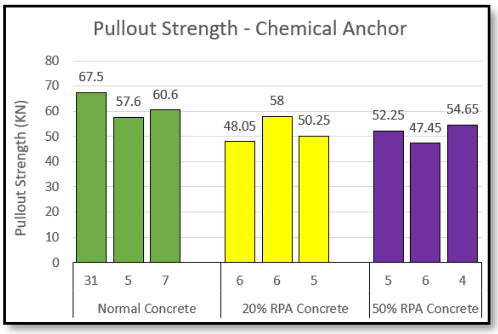

Figure 22: Comparison of Pullout Strengths

CONCLUSIONS

The compression test results for the standard concrete sampling are indicative of an N32 concrete sample. The tested anchor tension load capacities were equivalent to that expected, based on the anchor supplier documentation for the anchors utilised. This provided a good reference for the comparative testing of the RPA sampling and confirmed the relevance to real world conditions and general anchor usage. The 50% RPA concrete demonstrated significant capacity reduction and to the extent that it is obvious that utilisation of RPA at these rates cannot be sustained and would not be used in general construction or landscape structures. Testing this material was beneficial in a way that it provided good extrapolation of results beyond the substitution rates that have been adopted to date and permitted assessment of the potential to adopt higher substitution rates. The 20% RPA concrete demonstrated reduction in capacities that could conceivably to be tolerated in the construction industries. It effectively represents downgrading of the concrete by what is generally considered in the industry as 'one grade lower'. The reduced test anchor loads similarly are indicative of the expected anchor capacities inserted into concrete that is 'one grade lower'. This testing appears to support the current attitude that substitution rates of 10% are realistic and that substitution rates above 20% would not be considered viable from a capacity and performance perspective, and unlikely to also prove viable from a commercial perspective. This testing indicates that the anticipated design anchor capacities nominated by the suppliers would still be relevant for RPA concrete with substitution rate not exceeding 20% and capacities determined based on a concrete grade that is supported by the actual achieved concrete compression testing (one grade lower). The Mechanical anchors were noticeably more affected by the RPA substitution than the Chemical anchors. Subject to further detailed inspection, it appears that the RPA is effectively removed from the face of the drilled hole effectively reducing the area of contact between anchor and concrete. This reduction in contact area results in a relative reduction in achievable friction/ resistance and the resulting achieved pull-out load. These relative reductions can be compensated for by using the 'one grade lower' approach to design. Subject to further detailed inspection, it appears that the RPA is effectively removed from the face of the drilled hole, effectively producing ‘keying’ at the interface of concrete and adhesive and improving the mechanical interlocking between concrete and adhesive. There is strong confidence in the chemical anchor capacities will be retained but will be limited by the concrete reduced capacities. These anchor pull-out capacities can be confidently determined by using the ‘one grade lower’ approach to design. In regard to general anchor design, it is recommended a conservative design approach is adopted, such as:

- Use a proprietary RPA supplier.
- Use a base concrete blend of N20, N25 or N32.
- Adopt a ‘one grade lower’ design approach.
- Test concrete to confirm capacities achieve the ‘one grade lower’ category.
- Use a large volume anchor manufacturer and supplier.
- Use a readily available anchor available to general public.
- Utilise mid-sized bolts, M10 to M20.
- Adopt the supplier design capacities for a “one grade lower” category.
- Ensure supplier design minimum bolt spacing and edge distances are adopted.
- Develop redundancy into the bult group (avoid single bolt anchorage).
- Ensure the design and certification is provided by an appropriately experienced and certified engineer (RPEQ or appropriate equivalent).

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