Evaluation of the Durability of New Vertical Automated Cast Concrete Pipe against Machine-Made Concrete Pipe.

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Abstract: Steel reinforced concrete pipe is recognised as the most durable and economical solution for drainage pipelines and has been manufactured in Australia and New Zealand for more than 100 years. Two horizontal casting processes (centrifugal wet spinning and roller suspension) were developed in the early 1900s and these became the driving force of the concrete pipe manufacturing industry in Australasia.

The current Standard for the manufacture of concrete pipes in Australia and New Zealand is AS/NZS 4058:2007. Materials and manufacturing methods for producing pipes have developed over time, and in the late 1900's new manufacturing processes were introduced in Australasia providing increased efficiency and waste reduction. These included vertical dry cast processes such as roller compacted and vibrating core technology. More recent developments include a vertical highly automated manufacturing process (AutoCast) using SCC.

This paper reviews pipe manufacturing methods and evaluates durability testing of machine-made pipe against AutoCast manufactured concrete pipes. Results from laboratory and field studies of these different concrete pipes are evaluated to assess performance, quality and durability. Testing covered includes water absorption, apparent volume of permeable voids, carbonation, chloride migration, chloride diffusion and acid resistance and electrical resistivity. The durability tests undertaken show comparable results for concrete pipe across all manufacturing processes investigated. These meet the durability requirements of AS/NZS 4058: 2007 and all processes exceed those of standard cast in-situ concrete.

Keywords: Pipe, durability, acid attack, carbonation, chloride, absorption.

1. Introduction and Background

Steel reinforced concrete pipe is recognised as the durable and economical solution for drainage pipelines and these products have been manufactured in Australia and New Zealand for more than 100 years (1). Materials and pipe manufacturing techniques have developed over time. Two horizontal spinning processes (centrifugal wet spinning and roller suspension) were developed in the early 1900s and these became the driving force of the concrete pipe manufacturing industry in Australasia and world wide (2). These technologies produce thin walled concrete pipe and were a major driver of production efficiency and durability of concrete pipe in this region. The consistent quality and in-service performance of these pipes has been recognised over time and this superior performance over other precast concrete elements is reflected in the current manufacturing Standard AS/NZS 4058: Precast Concrete Pipes (pressure and Non-Pressure) (3).

In the 1960's and 1970's, development particulalry in the United States led to new manufacturing processes and systems with increased efficiency and reduced waste, such as the vertical dry cast radial press technology, now known as Bi-Di Packerhead or Rollerhead (4). Similarly new technnology was emerging in Europe such as vertical drycast vibrating core technology.

By the early 2000's there were a number of the numbers of processes for manufacturing pipes which included:-

- Horizontal centrifugal spinning;
- Horizontal roller suspension spinning;
- Vertical Bi-Di Packerhead;
- Vertical Vibrating Core;
- Wet cast (predominantly for some larger diameter pipes)

Prior to AS/NZS 4058: 2007, the earlier Standard AS 4198, made no mention of the manufacturing process. With the publication of AS/NZS 4058:2007 all that changed with the introduction of the terms “machine-made” and “wet cast”. No definitions of these terms were included other than wet cast had to be “50 MPa Concrete” (1, 2). Around 2007, machine-made was generally accepted as processes using very low or zero slump concrete with low water:binder ratio, placed in steel moulds and compacted by centrifugal forces, low frequency high amplitude vibration or by direct mechanical compaction (2). Wet cast suited the manufacture of larger diameter pipe (>2 m diameter), using conventional slump concrete placed in rigid steel moulds and compacted using either a combination of internal and external form vibrators, or external form vibrators alone.

AS/NZS 4058:2007 has larger cover requirements for wet cast pipe (25 mm) compared to machine-made pipe (10 mm) for Normal environments defined in that Standard. The higher covers for the larger wet cast pipes suited their manufacture as larger aggregates were typically used in the concrete mix and wall thicknesses were relatively large to start with due to load requirements on the pipe. This resulted in the cover as a percentage of the wall thickness being much less.

In the late 1990’s, self-compacting or super workable concrete started appearing first in cast in-situ construction and by the early 2000’s was being used for precast concrete products in Japan and Europe. This included a modern highly automated pipe manufacturing process using very controlled concrete batching, placing and curing techniques. The self-compacting or super workable concrete used in this process had much higher performance requirements than nominated in AS/NZS 4058:2007 for wet cast concrete. These requirements translated into a more durable concrete with hardened properties that are more closely aligned to concrete produced in the machine-made pipe manufacturing process.

A study was undertaken to compare of the quality and durability properties of concrete pipe manufactured using the high performance self-compacting concrete with pipe manufactured by a number of machine made processes. The machine made pipes included spun and Vertical Dry Cast Bi-Di Packerhead maufacturing processes. The durability parameters considered were:

1. Concrete strength;
2. Water absorption;
3. Apparent Volume of Permanent Voids (AVPV);
4. Chloride Diffusion and Migration;
5. Accelerated Carbonation, and
6. Resistance to Acid Exposure at 1% and 10% concentration.

2. Testing Program

The testing programme involved sourcing 600 or 675mm diameter concrete pipe from the standard production processes and coring test samples from the finished product. The cored test samples were cylindrical cores cut radially through the entire thickness of the concrete pipe wall with faces corresponding to the internal and external surfaces of the pipe.

The protocol followed was that developed by the CPAA for a testing programme carried out some years ago (1). Each set of cored test samples were extracted from 2 pipes, with cores uniquely identified such that individual test samples across all test sets always came from the same locations on the pipes. Test sets were cored from pipe samples manufactured using the the following processes:

1. Horizontal centrifugal spinning;
2. Vertical Bi-Di Packerhead VCT, and
3. Automated SCC.

All the cores were extracted from the pipe samples between 14 and 21 days from date of manufacture. After extraction the cores wrapped in a damp cloth or paper and placed in plastic bags for delivery to the testing laboratory.

Mix design details for concrete used in pipe manufacture are summarised in Table 1. The testing program was undertaken over a number of phases over a period of time from December 2018 to April 2021.

Table 1: Mix Designs Details of Pipe Test Specimens

Component	Unit	Spun	VCT	Automated SCC
Binder Content	kg/m3	>350	>400	>500
w/b Ratio	-	<0.4	<0.4	≤0.35

Note: Superplasticisers and slump retention admixtures were used in all concretes.

3. Laboratory Testing

The testing was carried out by an independent testing laboratory, with all the testing commencing at an age of 28 days after manufacture.

3.1 Water absorption

The water absorption was carried out in accordance with AS/NZS 4058: 2007 – Appendix F- Absorption test for concrete pipe (3). The test is an Industry standard classification and quality control test for precast concrete pipe. It is the only durability parameter test required by AS/NZS 4058: 2007. The test measures the increase in weight of oven dried samples after boiling in water for 5 hours.

3.2 Apparent Volume of Permeable Voids (AVPV)

This test was carried out in accordance with AS 1012.21 (5). It measures the volume of permeable voids within the concrete by weight increase due to absorption from dried to boiling conditions. Details of the test and how it can be used to assess concrete performance are described in the literature (6, 7).

3.3 Chloride Diffusion and Migration

Chloride diffusion and migration testing were carried out in accordance with Nordtest Build 443 (8) and Nordtest Build 492 (9) test methods respectively. The former test provides the diffusion rate of chlorides whilst the latter test provides the migration rate of chlorides into the concrete specimen.

3.4 Accelerated Carbonation

Accelerated carbonation testing was undertaken to a test was carried out in accordance the independent testing laboratory in-house procedure which is equivalent to the EFNARC method. This test provides a comparative indication of the carbonation rate of the different concrete sample.

3.5 Acid resistance

This test was carried out in accordance with the independent testing laboratory in-house method for both 1% and 10% H_2SO_4 acid solutions. Loss measurements were carried out at regular intervals up to 10 and 26 weeks for 10% and 1% H_2SO_4 acid solutions respectively. The test provides a comparative indication of the resistance of the concrete to an aggressive acidic environment.

4. Test Results

This testing programme measured the same durability parameters across a range of machine-made manufacturing processes which included:

- Horizontal centrifugal spinning;
- Horizontal roller suspension spinning and
- Vertical Vibrating Core.

These are compared with the upper and lower values of data collected by the Concrete Pipe of Australasia (CPAA) from a testing programme carried out in 2015 and 2016. The test results from the various testing phases are detailed below.

4.1 Water absorption

The water absorption was carried out in accordance with AS/NZS 4058: 2007 – Appendix F - Absorption test for concrete pipe. Data for concrete samples taken from the different pipes are described in Figure 1. As expected, all concretes conform to the requirements of limits set in AS4058 (<6%) and are generally

within the range of values derived by the CPAA study that are reflective of concrete currently used in machine-made pipe manufacture.

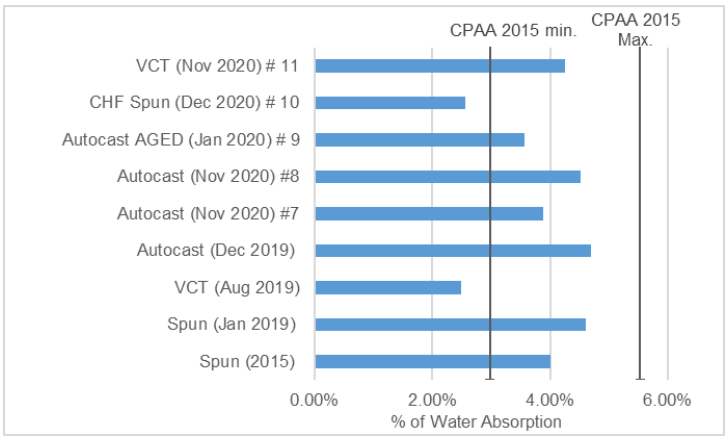


Figure 1. Water absorption.

4.2 Apparent Volume of Permeable Voids (AVPV)

Data for AVPV on samples taken from concrete pipes investigated in this study are presented in Figure 2. The most commonly used guidelines for this test are provided in VicRoads Specification 610, which is discussed in Concrete Institute Recommended Practice Z7-07 (6). AVPV performance assessment criteria for structural applications in this specification nominate a maximum value of 14% for cores for concrete having a characteristic compressive strength of 55 MPa. Data in Figure 2 shows that for all pipe concretes investigated results were within a range of 8% to 14%. This is significantly lower than the limit noted. In addition, AVPV data for concrete from the pipes investigated was within the range found in the CPAA study of commercial pipe concrete in 2015.

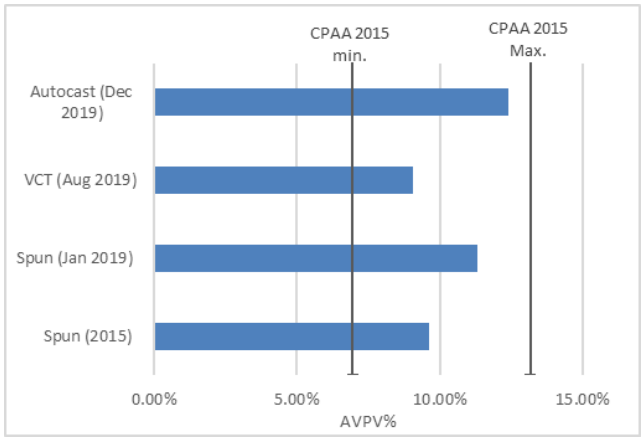
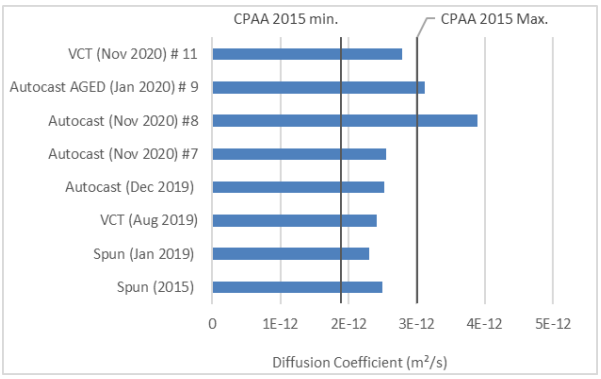


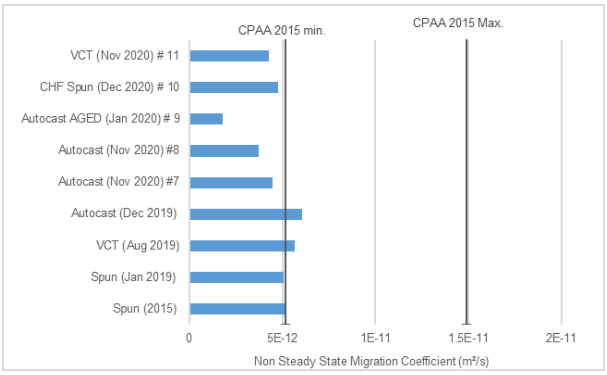
Figure 2. Average volume of permeable voids.

4.3 Chloride Diffusion and Migration

The results for both NT Build 443 and 492 are presented in Figures 3(a) and 3(b) respectively. Chloride ingress is not considered critical in a normal environment as defined in Appendix E of AS/NZS 4058: 2007 where the chloride ion concentrations in the soil are < 20 000 ppm (3). Chloride diffusion was assessed using the NT Build 443 test method having 35 days of exposure to chloride. This is a very short timeframe for significant levels of chloride to ingress into concrete. Therefore, given this early age, some variations can be expected in the data (6, 10). It was found that the difference in the derived chloride diffusion coefficient between spun concrete and the vertical cast concretes is marginal and within the testing error of NT Build 443. Further, the range of chloride diffusion values found in the CPAA study of 2015 were similar to values derived in this study with the exception of two samples. Chloride migration data for the set of pipe concrete investigated in this study were generally lower than those determined for pipes in the CPAA study of 2015.



(a) Chloride diffusion (NT Build 443)



(b) Chloride migration (NT Build)492)

Figure 3. Chloride diffusion and migration.

4.5 Accelerated Carbonation

Carbonation testing is undertaken under accelerated conditions and therefore the results are indicative of the relative carbonation rates. Accelerated carbonation testing is highly variable particularly over the short time frame over which the measurements are taken. The accelerated test method is not representative of the actual service conditions of the pipe and cannot be used to directly infer the performance of the pipe in-situ. Carbonation is generally considered low risk for pipes as carbonation is limited in regions of high humidity typical of the internal and external environments of the pipe. Carbonation is only of concern in arid areas where the internal pipe has long dry periods where carbonation can occur. In Figure 5, data for carbonation for all concretes investigated in this study were relatively low and significantly lower than that derived for concrete in pipes investigated in the 2015 CPAA study, and lower than for 50 MPa cast in-situ concrete.

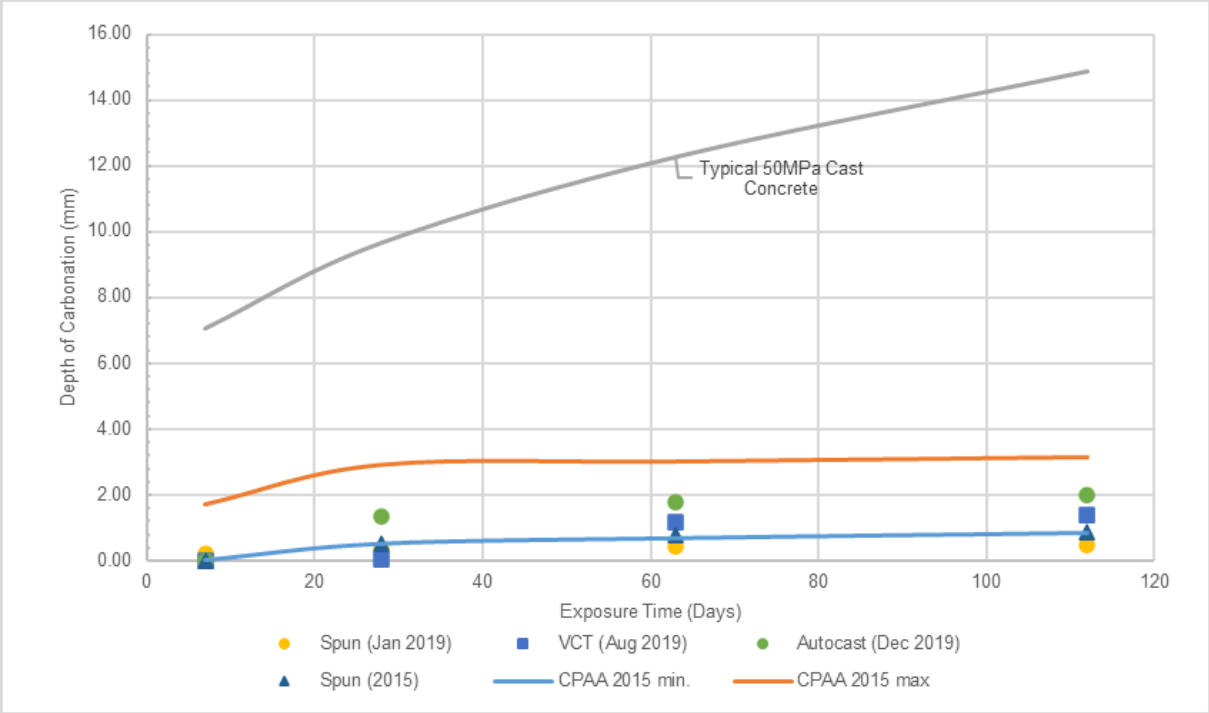


Figure 4. Accelerated carbonation.

4.6 Acid resistance

The resistance of the concrete to acid attack, shown in Figures 5 and 6, provides a comparative assessment of the various concrete compositions associated with the different manufacturing processes. The testing is not related to the resistance of the concrete to acid sulphate soil exposure. The resistance of the concrete to acid sulphate soils is largely based on prescriptive mix requirements. Data in Figures 5 and 6 show that for 1% H_2SO_4 exposure and 10% H_2SO_4 exposure, the difference between spun pipe concrete and AutoCast pipe concrete was similar, and below the values derived from the 2015 CPAA study.

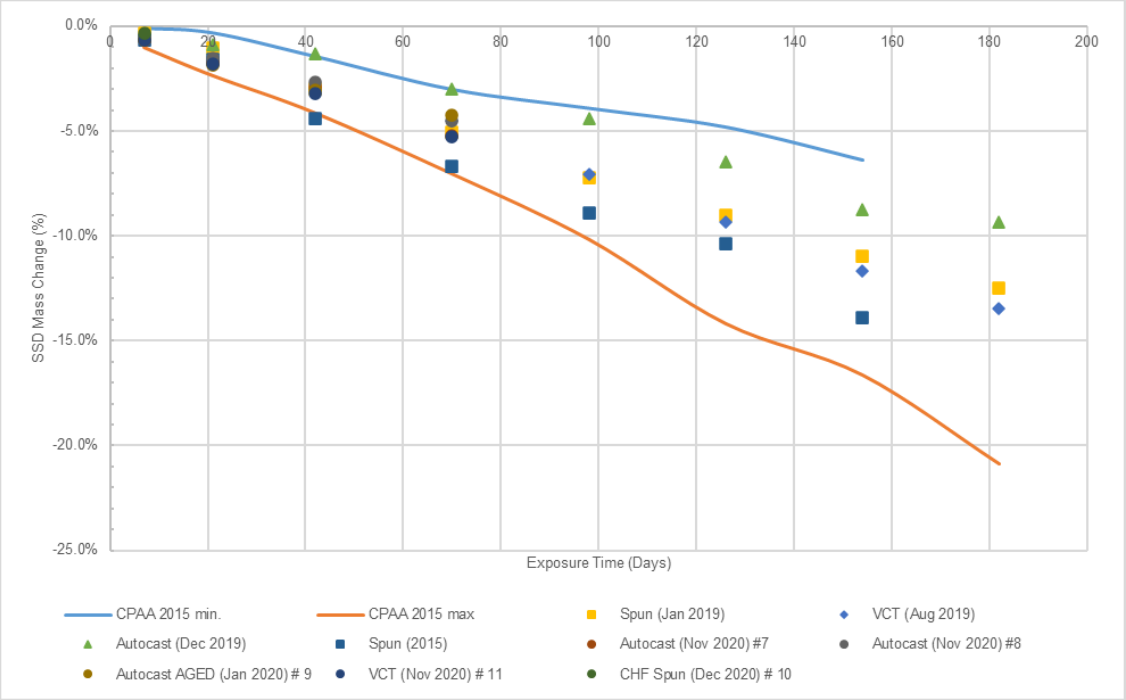


Figure 5. Resistance to 1% H_2SO_4 Exposure.

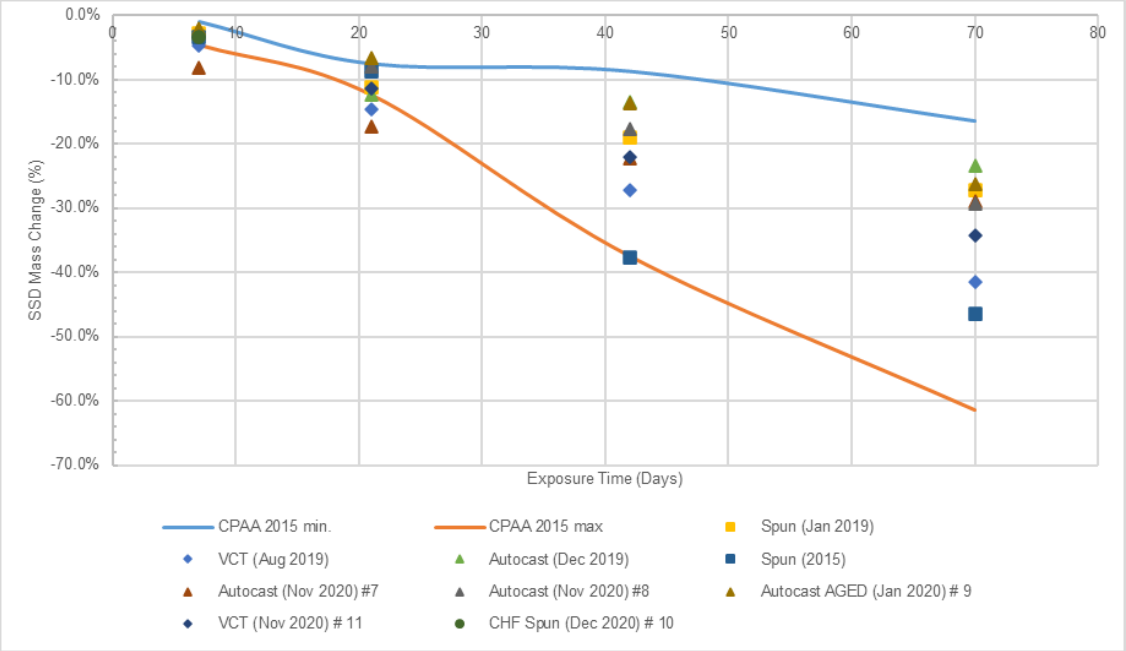


Figure 6. Resistance to 10% H_2SO_4 Exposure.

5. Conclusions

This study compared the durability of concrete pipe cores from two machine made manufacturing processes (Spun and Vertical Bi-Di Packerhead) with cores from concrete pipe manufactured using SCC in an automated production process. These results were also benchmarked against similar durability tests results from a CPAA test program which covered a wider range of machine-made concrete pipe. The following test results were compared:

- Water absorption;
- Apparent volume of permeable voids (AVPV);
- Chloride diffusion using Nordtest Build 443;
- Chloride migration using Nordtest Build 492;
- Carbonation, and
- Resistance to Acid Exposure at 1% and 10% concentration.

The tests were performed on cores extracted from actual pipes manufactured whilst testing of standard concretes are generally extracted from laboratory cast cylinders. Therefore, comparisons between data for standard concretes do not necessarily directly compare with that of pipe concrete. However, the results show there is a significant difference between the quality of concrete used to manufacture concrete pipe and that supplied for general structural concrete (conforming to NZS 3101 and AS 3600). The results show that all pipe manufacturing methods reported meet the durability requirements of AS/NZS 4058: 2007. The other durability tests undertaken show comparable results for pipe concrete across all manufacturing processes considered.

6. Acknowledgement

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