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Case Study - Fusion parameters for large diameter PE pipes

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SUMMARY

The impact of varying butt fusion parameters for large diameter thick-walled PE100 pipe is investigated. Joint quality is assessed using tensile strength, visual assessment of tensile specimens and Oxidation Induction Time. The results provide confidence that varying fusion parameters within the specified envelope has no detrimental impact on joint quality.

KEYWORDS

PE100, POP003, Butt fusion parameters, large diameter PE pipe, ISO21307.

ABSTRACT

In 2023 PIPA undertook an extensive revision of their Industry Guidance document known as POP003 Butt Fusion Jointing of PE Pipes and Fittings – Recommended Parameters and Practices [(1)]. This revision introduced a new section providing additional guidance around best practices for butt fusion. One of the best practice elements focused on optimising the fusion parameters particularly as PE pipelines are increasingly being used in larger diameter critical applications.

A group of PIPA members collaborated to examine the impact of differing parameters within the ISO 21307 Plastics pipes and fittings — Butt fusion jointing procedures for polyethylene (PE) piping systems [(2)]. The work specifically focused on the single high pressure fusion envelope to see if additional detail could be provided in relation to optimising outcomes. A DN800 SDR11 PE100 pipe was fused using a range of different parameters, sectioned and destructively tested. This paper details the outcome of that work and draws conclusions about fusion of large diameter PE100 pipe.

INTRODUCTION

The use of polyethylene (PE) pipe continues to grow with larger diameter and thicker wall pipe applications now commonplace across gas and water infrastructure, mining and irrigation sectors. The most common jointing method for PE pipe is butt fusion and with increasing diameter and wall thickness there is often a need to optimise fusion parameters within the envelope of standard specifications.

The Plastics Industry Pipe Association of Australia (PIPA) recognised the need for greater guidance in this area and in 2023 comprehensively revised its publication POP003 -Butt Fusion Jointing of PE Pipes and Fittings – Recommended Parameters and Practices. During the process of revising the PIPA POP003 guideline, advice was provided by a range of industry experts involved across the full spectrum of PE pipeline stakeholders – raw material suppliers, pipe manufacturers, fusion welding contractors, fusion welding equipment suppliers and fusion weld assessment specialists. This advice supported the need to raise the profile for optimising fusion parameters within the recommended boundaries of ISO 21307 Plastics pipes and fittings — Butt fusion jointing procedures for polyethylene (PE) piping systems. The need to optimise fusion parameters is typically due to specific environmental conditions or constraints on site, addressing specific needs of the pipe being butt fused or constraints of the fusion equipment being used.

Following on from the POP003 revision a number of PIPA member companies collaborated to explore some of the optimisation options within the ISO 21307 Single High Pressure (SHP) fusion parameter envelope. In Australia the ISO 21307 SHP parameters are increasingly used for large diameter thick-walled pipe due to the reduced fusion cycle times - hence this project focused solely on the SHP fusion envelope.

This project is intended to be relevant for all quality PE100 materials used in the manufacture of large diameter thick walled pipe. Specifically in this case the commonly used Polymer Direct SCG Chemical H112PC material was employed in the manufacture of the pipe. This material has been listed in the PIPA POP004 Polyethylene pipe and fitting compounds document [3] since 2015 as a fully compliant PE100. This material is one of the most commonly used grades of PE100 for pipe applications in Australia and often used in large diameter thick-wall pipes hence represents a good example of material used extensively in the gas, water and mining sectors.

Vinidex manufactured the DN800 SDR11 pipe at their Toowoomba facility in Queensland as part of a normal production run. The pipe used for the project was one taken from routine production and not specially manufactured in any way.

A project of this type is extremely difficult, if not impossible, to undertake within the constraints of a commercial pipeline installation. Therefore the fusion welding was undertaken at GEM Industrials Leongatha facility in Victoria. They are well credentialed PE pipe fusion welding contractors with the necessary equipment and experience to fuse pipe of this dimension.

Iplex Pipelines carried out all testing at their NATA registered laboratory in Sydney and are well credentialled and experienced in the testing and assessment of butt fusion welding.

FUSION PARAMETERS

As with all standard fusion parameters there are ranges of accepted values that can be used within the specified envelope. Under actual site conditions it may be necessary to optimise the parameters within the specified envelope to improve the jointing outcome.

In terms of fusion parameters normally the starting point would be the mid-point of the temperature and pressure ranges with the heat soak time determined using the nominal wall thickness as specified in ISO 21307. These parameters represented the Control Condition used in this project.

Based on the advice from experts consulted as part of the revision of POP003, under circumstances where fusion parameter optimisation is needed the logical steps would involve increasing heat input and minimising the amount of material forced out in the fusion process. This can be achieved in a number of ways:

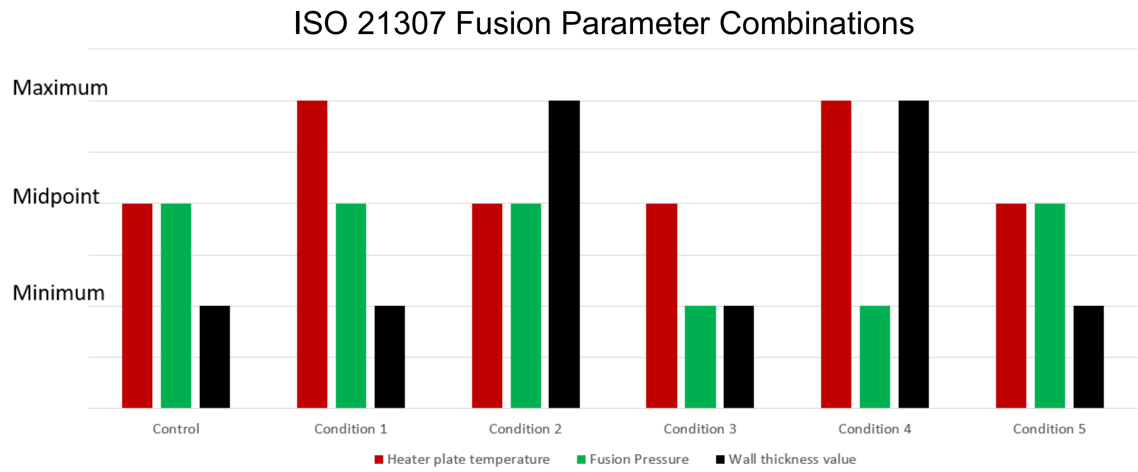
- increasing heat input by increasing the heater plate temperature to the maximum permitted in the SHP envelope – i.e. 230^{0}C.
- increasing heat soak time by using the maximum wall thickness value rather than the nominal value for wall thickness specified in ISO 21307.
- reducing the fusion pressure to the minimum value of 0.42MPa to minimise the amount of hot material forced out of the fusion interface.

These options aligned with previous work done by SCG Chemical using DN315 SDR9 pipe [(4)].

It was also decided to include a condition employing a McElroy proprietary cooling calculation in place of the ISO 21307 requirement. This condition is outside the ISO 21307 Standard but given the desire to minimise fusion cycle times it was believed this was a useful addition to the test program and an opportunity to assess if there was any impact to joint quality.

The test program therefore followed these conditions:

- <u>Control Condition</u> : mid-point settings for temperature and pressure and heat soak determined using nominal wall thickness as specified in ISO 21307 SHP.
- <u>Condition 1</u>: Increase heater plate temperature to maximum recommended value
- <u>Condition 2</u> : Increase heat soak time by using maximum wall thickness as the basis for the parameter calculations
- <u>Condition 3</u> : Reduce jointing pressure to minimum recommended value
- <u>Condition 4</u> : Combine Conditions 1, 2 and 3.
- <u>Condition 5</u> : same as Control Condition but use proprietary cooling calculation.



BEST PRACTICE

The pipe and fusion welding conditions used for this work represented best practice.

The raw material and pipe were compliant with the relevant product standards. The DN800 SDR11 pipe had no measurable ovality and was dimensionally consistent with the wall thickness ranging from 75.3 to 80.0mm.

The fusion welding was carried out using an experienced contractor in a factory environment with well-maintained calibrated equipment. The fusion machine was a McElroy TracStar 900 HF. The ambient temperature was consistent varying between 15^0C and 18^0C. All cutting was done using unlubricated chain saws. Before each fusion the heater plate was checked for cleanliness and temperatures measured using an optical pyrometer in each quadrant of both sides of the heater plate. Whilst it is appreciated there are differing views on the need to clean the planed surfaces of the pipe ends – in this case all planed ends were wiped with recommended alcohol wipes before each fusion weld. Whilst the pipe ends were open in this project it should be noted jointing was conducted inside a building. The photograph below shows the fusion location.

RESULTS

Tensile Testing

All fusion welds were sectioned into 7 samples equally spaced around the circumference and tensile tested in accordance with ISO 13953 Polyethylene (PE) pipes and fittings – Determination of the tensile strength and failure mode of test pieces from a butt-fused joint [5].

Each of the 7 samples for each fusion condition were examined in terms of the appearance of the fracture surface and assessed. The load v extension curves were also reviewed for each sample.

Results for each condition are detailed in Appendix A where the load v extension chart is shown for each fusion weld and photographs representative of the appearance of the fracture surfaces.

A summary of results is shown in Table 1.

Table 1 Summary of tensile test results

Sample Identification	Range of tensile results across 7 samples expressed as % of parent pipe tensile strength	ISO 13953 Assessment	Load v extension curve assessment
Control Condition	94 -101%	All Samples Ductile	All Samples Ductile
Condition 1	94 - 99%	All Samples Ductile	All Samples Ductile
Condition 2	94 - 98%	All Samples Ductile	All Samples Ductile
Condition 3	94 – 96%	All Samples Ductile	All Samples Ductile
Condition 4	95 – 100%	All Samples Ductile	All Samples Ductile
Condition 5	91 – 97%	All Samples Ductile	All Samples Ductile

Oxidation Induction Time (OIT) results

When fusing thick-walled PE pipes questions are often raised regarding what a reasonable upper limit for the heat soak time is, which is not defined in ISO 21307. Increasing heat soak time in conjunction with applying the upper limit of fusion temperature has the potential to excessively consume the PE materials antioxidant package which may in turn compromise long-term thermal stability and potentially the long-term performance of the fused pipeline, if insufficient antioxidants remain in the fusion zone. Consequently, the project included an assessment of fusion zone oxidation times and compared those results to OIT results obtained from the unfused pipe referred to as 'Parent' material.

Oxidation Induction Time Testing Methodology

OIT test samples in the form of discs with a wall thickness of 0.65 ± 0.1mm were taken from five positions within the fusion zone and across the entire wall section of the pipe. Five OIT test samples were also taken from an unfused section of the pipe at the same intervals across the pipe wall thickness. These samples represented the 'Parent' material of the extruded pipe.

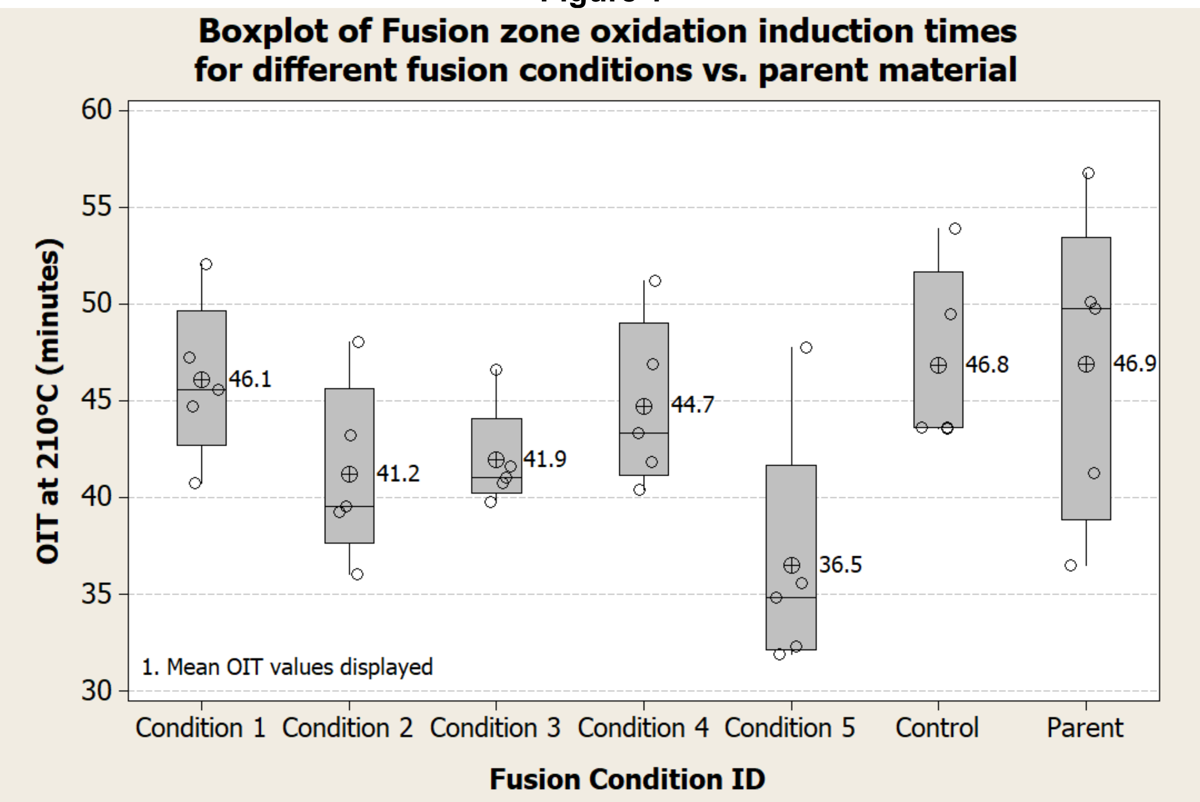
Isothermal oxidation induction time tests were carried out at a test temperature of 210°C using a Mettler Toledo DSC 1 differential scanning calorimeter. Testing was carried out in accordance with ISO 11357-6 Plastics – Differential scanning calorimetry (DSC) – Part 6: Determination of oxidation induction time (isothermal OIT) [(6)]. High purity nitrogen flowing at 50 ml/min was used as the purge gas and high purity oxygen was used as the oxidising gas. OIT exotherms were evaluated using the off-set analysis method at a threshold distance of 0.05 W/g.

Analysis of OIT Results

The parent material samples taken from across the wall section of the pipe have a mean OIT at 210°C equal to 46.9 minutes and standard deviation of 8.00 minutes. For the six fusion conditions studied, fusion zone mean OIT at 210°C ranged from 36.5 – 46.8 minutes as can been seen in figure 1 - Boxplot of Fusion Zone oxidation induction times.

Paired t-tests at a 95% confidence interval were carried out to assess if there is any significant difference between fusion zone mean OIT results and the mean OIT result for the parent material. Resultant p-values for the seven conditions ranged from 0.149 to 0.991 indicating no significant difference in mean OIT at the fusion zone versus the parent material (unfused pipe). For all six fusion conditions tested there are equivalent levels of antioxidants remaining in the fusion zone as there are in the parent material. It is also evident that the PE material has been formulated with a high degree of robustness to thermal stability which will be advantageous where heat soak times need to be increased in conjunction with the upper limit fusion temperature.

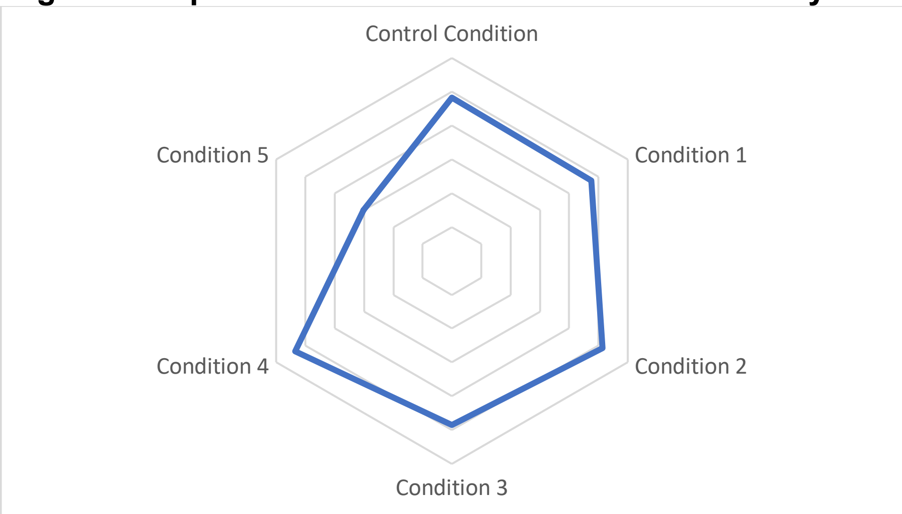
Figure 1



Comments

1. All fusion welds exhibited ductile behaviour in the destructive tensile test. All fracture surfaces for each of the 7 samples of each joint were unequivocally ductile and consistent in appearance.
2. All samples from every fusion weld exhibited a consistent and clearly ductile load v extension curve.
3. All samples from every fusion weld exceeded the 90% minimum tensile requirement when compared to the parent pipe tensile strength.
4. OIT testing indicated even though temperature and heat soak times were maximised this had no detrimental effect in terms of thermal stability of the pipe.
5. There was minimal variation in bead size and shape. All beads were normal in appearance regardless of the fusion conditions.
6. The dimensional consistency of the pipe wall resulted in variations in heat soak times from approximately 13 minutes using the nominal wall value specified in ISO21307 to approximately 14 minutes when the maximum wall thickness value was used in the calculations. Under circumstances where pipe wall thickness has greater variability there would consequently be an increased impact on the heat soak times than occurred in this case.
7. Employing the maximum wall thickness for calculations increases both heat soak and cooling times. The impact on total fusion times was however minimal across Control and Conditions 1 through 4. Heater plate temperature and fusion pressure changes do not impact the cycle times. The only significant impact on total fusion time was seen in Condition 5 where the proprietary cooling calculation was used. This calculation effectively halved the cooling time under pressure. It must be noted that this cooling time is outside the ISO21307 specification.

Figure 2: Impact of fusion condition on total fusion cycle time



CONCLUSIONS

1. This work was done using best practice products, people, equipment, environmental conditions and procedures. The result validates the suitability of

the ISO 21307 SHP parameters for what is a representative PE100 material commonly used in large diameter thick-walled pipe. It also confirms the fusion processing window for quality PE100 pipe is broad based when jointing under these conditions.

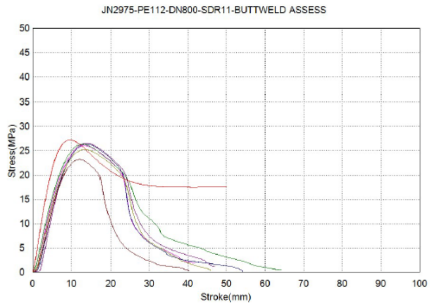
2. Under these conditions optimisation was not necessary as the initial control condition resulted in fusion welds that comprehensively pass the ISO13953 requirements. Under these conditions this was the expected outcome.
3. Conditions 1,2,3 and 4 were at the extremities of the ISO21307 SHP fusion envelope but still resulted in fusion welds that pass the ISO13953 requirements, exhibited OIT results well above any level of concern and importantly did not cause any detrimental impact to the joints. This provides confidence that quality PE100 pipes can be fusion welded if needed for optimisation purposes using these upper boundaries of temperature and heat soak and similarly using the lower boundaries of fusion pressure.
4. When considering Condition 5 parameters the cooling time under pressure was reduced by approximately 55% in this case with an overall reduction in fusion cycle time of 37.5% compared to the Control Condition. The results from tensile testing and OIT show there were no observed detrimental impacts from using the proprietary cooling calculation when fusion welding under these conditions.
5. Whilst in this project all samples were unequivocally ductile in appearance, the greater use of the load v extension curve as an integral part of the assessment process is to be encouraged to assist in dealing with the sometimes difficult subjective assessment of sample fracture surfaces.
6. Based on the outcomes of this work at this point there was no additional guidance that could be recommended for inclusion in POP003.

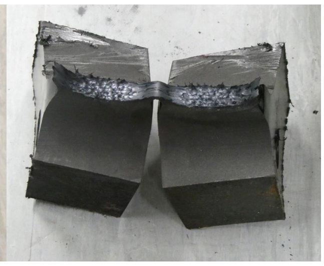
REFERENCES

1. Plastics Industry Pipe Association of Australia (PIPA). *POP003 Butt Fusion Jointing of PE Pipes and Fittings – Recommended Parameters and Practices.* https://pipa.com.au/technical/pop-guidelines/.
2. International Standard. *ISO 21307 Plastics pipes and fittings — Butt fusion jointing procedures for polyethylene (PE) piping systems*. https://www.iso.org/standard/
3. Plastics Industry Pipe Association of Australia (PIPA). *POP004 Polyethylene pipe and fitting compounds* . https://pipa.com.au/technical/pop-guidelines/
4. Private communication SCGC 2023
5. International Standard. *ISO 13953 Polyethylene (PE) pipes and fittings – Determination of the tensile strength and failure mode of test pieces from a butt-fused joint.* https://www.iso.org/standard/
6. International Standard. *ISO 11357-6 Plastics – Differential scanning calorimetry (DSC) – Part 6: Determination of oxidation induction time (isothermal OIT).* https://www.iso.org/standard/

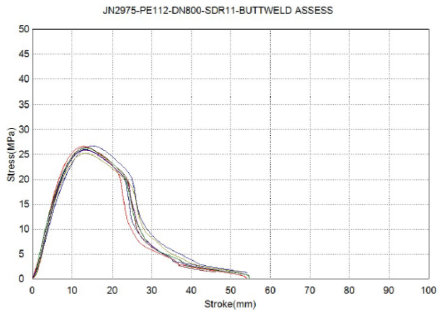
APPENDIX A
Tensile Test Results for each condition showing load v extension curve and representative photographs of tensile specimens for each condition and the parent pipe

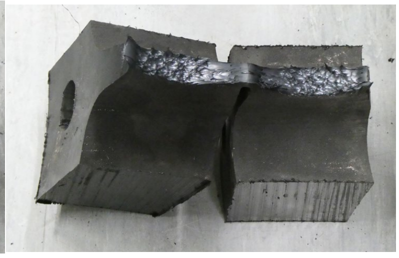
Control Condition



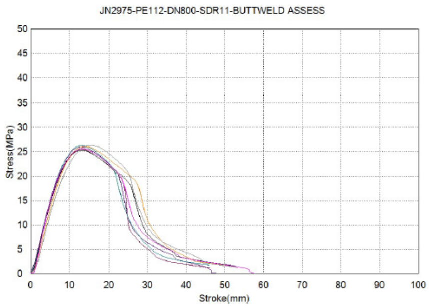



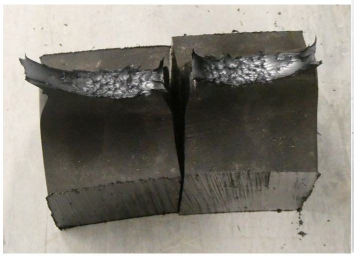
Condition 1



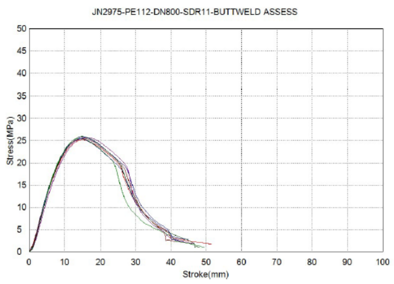



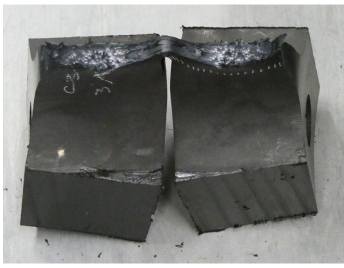
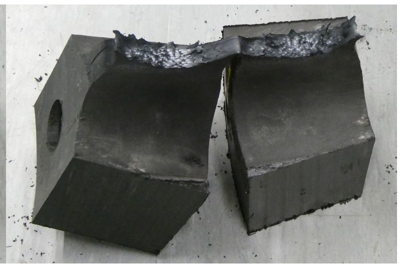
Condition 2



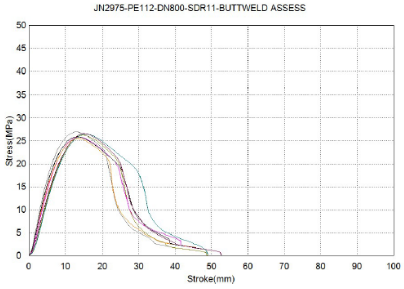



Condition 3

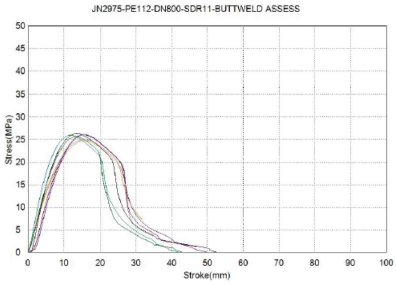


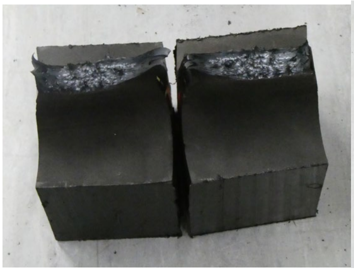



Condition 4

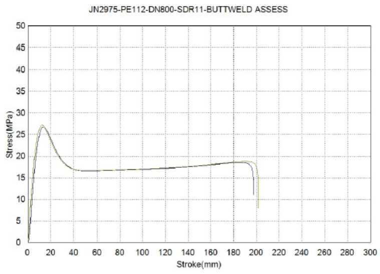


Condition 5





Parent pipe



Average tensile strength of two samples 26.9MPa