Effect of Welding Parameters on the Structural Performance of Fusion Welded Extruded and Injection Molded HDPE Joints

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***Abstract*--High Density Polyethylene (HDPE) is one of the most common materials that are used across a variety of applications due to its initial material cost and excellent chemical resistance. HDPE are traditionally used to form long installation pipes buried under infrastructure to form water mains, sewers and gas pipelines. While laying the HDPE pipes at any construction sites, joining or welding is a necessity for both extruded and injection molded pipes. Design engineers must consider this factor into consideration as using the tensile strength of the parent HDPE material while designing may lead to design failures. Fusion welding is carried out for the purpose of joining of pipes. The basic principle of fusion welding is that the ends of both pipes are heated and then fused together. Various parameters affect the strength of the joint. This research is based on the study of varying welding parameters and its affect on the structural performance of the joints. Tensile testing is carried out to check the structural integrity of the pipes after they have been fused together. In this research small HDPE strips were machined out from the pipes which were fusion welded by test setup developed locally to form joints with varying bead heights and thicknesses. Heating temperature and heating soak time were both varied to form different samples, machined out to avoid any discontinuity. The samples were then tested and results compared so that welding parameters and conditions of the HDPE joints are established such that the joint exhibits the same structural properties as that of the original pipe.**

1. Introduction:

The use of polymeric materials has widely increased due to their significance for light weight structures, low cost and its chemical resistance. Commonly the HDPE pipe sections are butt fusion welded where both pipe ends are heated and fused together. This requires establishing reliable standard test procedures for evaluating the mechanical properties of welded joints [1]. The understanding of weld joint is also important to confidently predict the service life of a pipe system. This becomes more important as industries move to more critical and challenging service conditions [1, 2]. It has been studied that fusion welds are influenced by various parameters i.e. alignment of samples, heater plate temperature, heating time, heater plate removal time, joint cooling time [2]. The values of these parameters may vary with material, diameter and pipe wall thickness [3, 4, 5]. It is established that joints made following standard procedures and in optimum environmental conditions have mechanical properties approximately as good as those of the parent pipe [6, 7]. However improperly fusion welded HDPE joints can be the weakest links in the pipelines [8, 9]. The quality of fusion joints becomes more important in high pressure applications i.e. type IV composite CNG cylinders [8, 10]. These composite CNG cylinders use fusion welded HDPE liners that are over wrapped with composite fiber.

Different manufacturing processes are available for producing components using the HDPE material i.e. extrusion, injection molding etc. Present studies cover effect of weld parameters on the performance e of fusion joints made between extruded HDPE samples. However no work has been done that correlates the fusion joint performance between extruded and injection molded HDPE samples. The present research aims to study the effect of changing weld parameters on fusion welds in extruded and injection molded HDPE samples. Standard tensile test that is most frequently used industry standard for evaluating the structural performance of fusion weld joints is used for comparing the weld performance.

2. Experimentation:

2.1 Material Preparation

Flat strips of HDPE material are prepared by machining of HDPE pipe (PN8, DN: 355mm, Thickness: 16.9mm) as shown in Fig 1. The machining of HDPE pipes is carried out in longitudinal direction and this direction is also the same in which these pipes are extruded. Flat strips obtained from these pipes are referred to as ***extruded HDPE strips***. The HDPE pipes used for machining are locally manufactured using HDPE grain (BroSafe HE3490-LS-H, also classified as PE100). The said HDPE grain material is produced by one of the leading polymer material manufacturer Borouge Pte Ltd. During machining of HDPE pipe, it is ensured that the machined surfaces have good surface finish and no discontinuity is present on the machined surfaces. For this purpose the machining of the samples is done with a depth of cut less than 1mm and at very low feed rates [11].

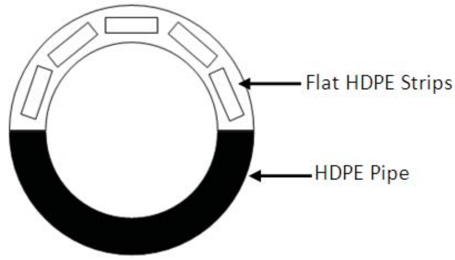


Figure 1: HDPE pipe section

2.2 Test setup for fusion welding

The machined flat strips can now be fusion welded with the help of a welding fixture. To fulfill this purpose, an in-house butt fusion welding test setup was developed as shown in Figure 2. The test setup consists of a heating plate having three heating elements and a clamping fixture. The temperature of heating plate is adjustable using a microcontroller that can operate with a tolerance of +1 ^{0}C. The presence of microcontroller will ensure accurate heating of plate and the same setup will be used for changing weld parameter study. Joining force required for fusion welding is applied manually with the help of a lead screw that is mounted on the welding fixture. The developed fusion welding fixture is very similar to the standard butt fusion welding machines used for joining of HDPE pipes as shown in Fig 2. Once the flat HDPE strips are machined and the welding fixture is available. Fusion joints can be made between the machined extruded HDPE strips by varying welding parameters (heating temperature and heat soaking time). The reason for considering only these two parameters is based on the already done research that explains that both these factors affects the quality of weld in a fusion joint the most [12, 13]. It is also assumed that since the joints are being made in a laboratory so no environmental effects i.e. dust contamination will affect the quality of welds.

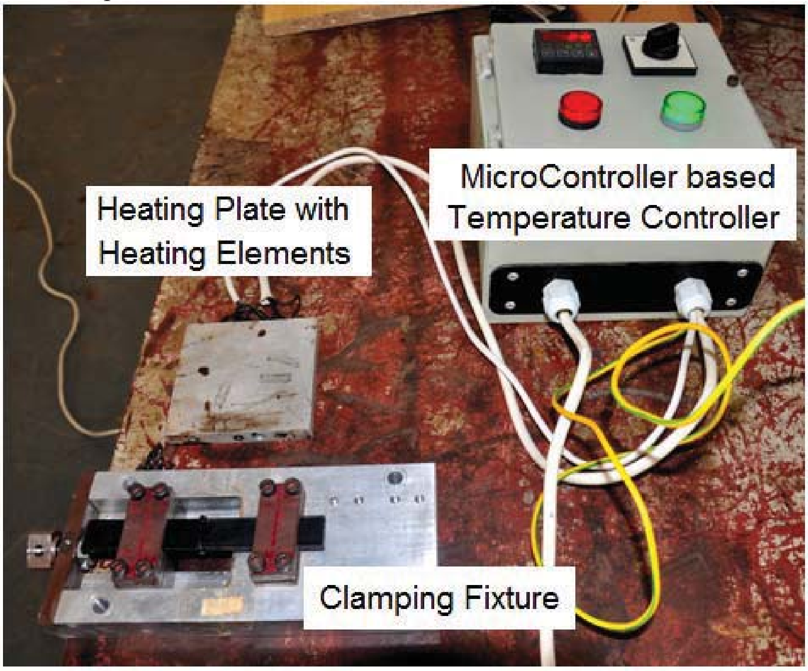


Figure 2: Developed fusion welding fixture

2.3 Tensile Testing

The strips made through the Fusion Welding joint are then machined to obtain the tensile specimens which are to be tested. The machining of strips removed weld beads from the tensile samples and weld joint line is exposed.

It is ensured that during machining no discontinuities are available on the tensile samples particularly at the joining location may result in stress concentrations at that point and will lead to discrepancies in the results. Later the samples are prepared for microscopy using sand paper of sizes 1, 2, 3 respectively. Microscopy of the tensile samples over the weld line is carried out to find out any lack of fusion at the joining line. The tensile samples are later tested in uni-axial direction at room temperature (25^{0}C) using a computerized MTS 210 tensile testing machine with extensometer having a gauge length of 25 mm. The displacement rate for this testing is kept constant as 50mm/min (ASTM D638). The tensile specimens are held between the fixed and movable grips. The samples are aligned to ensure that the long axis of the test specimen coincides with the direction of applied displacement and no slippage occurs at the grips. At least three specimens are tested for each combination of welding parameters. The tensile testing machine used has a constant rate of crosshead movement with fixed and moveable grips. The process is repeated for all test cases and results are listed in next pages.

Figure 3: (a) Fusion welded HDPE strips, (b) Machined fusion weld tensile samples

3. Analysis of tensile data

3.1 Stress-Strain curves

The resulting stress – strain curve for both types (extruded-extruded & extruded-injection molded) fusion welded tensile samples are presented in Fig 4 and 5. Studies show that the mechanical properties of a good fusion joint are as good as of the parent material [6, 7, 13]. To compare the results of fusion welded HDPE joints, tensile samples of the parent HDPE material was also tested. Figure 4 and 5 shows that stress strain curve for both types of samples (extruded-extruded & extruded-injection molded) show identical behavior, however the resulting values for tensile strength and percentage elongation at fracture are different for both these types. Studies suggest that if fusion joint results in a concave weld bead the joint will be of low quality. These low quality fusion joints are a result of improper applied pressure during the heating process [14].

The resulting weld beads for all the samples during present research work are convex, thus all the joints can be termed as good quality joints. Studies have also shown that for proper fusion welded joints the weld beads are round and of uniform sizes across the weld length [14]. The assumption is only valid for fusion joints made between similar materials. In case of fusion welds between dissimilar materials, the hypothesis does not hold true i.e. fusion joints made between materials that are produced through different manufacturing process. Examining the resulting weld beads the same phenomenon is observed with uniform weld bead sizes for extruded-extruded samples and non-uniform weld bead sizes for extruded-injection molded samples.

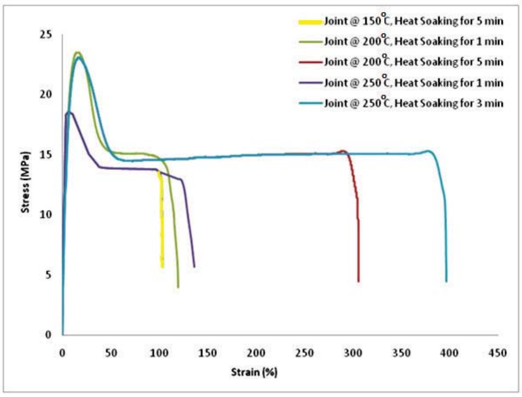


Figure 4: Stress – strain curve (extruded-extruded joints)

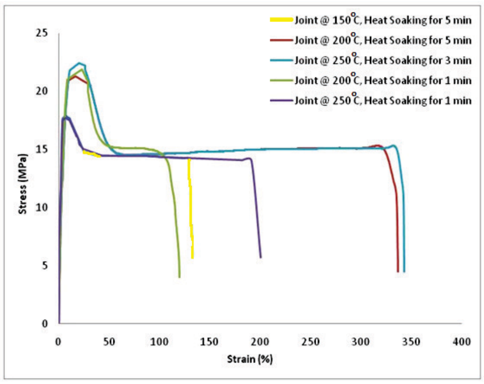


Figure 5: Stress – strain curve (extruded-injection molded joints)

3.2 Result Analysis for Changing Fusion Welding Parameters

To study the effect of changing welding parameters the results obtained from the experimental work are plotted in next sections. Figures 6, 7, 8 and 9 shows the effect of weld parameters on the weld bead thickness for joints made between extruded-extruded and extruded-injection molded materials respectively.

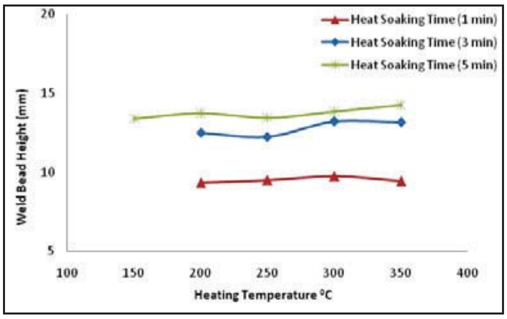


Figure 6: Effect on weld bead height (extruded – extruded joint)

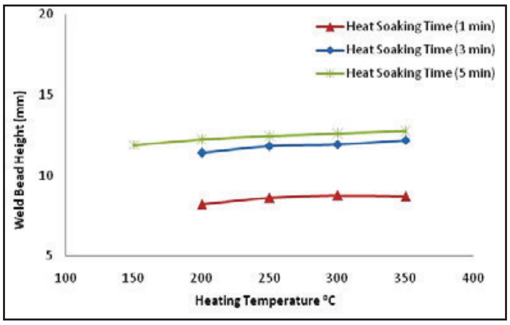


Figure 7: Effect on weld bead height (extruded – injection molded joint)

It is observed that the weld bead thickness shows a linearly increasing trend for all weld parameters in case of fusion joints made between extruded-injection molded samples. However for extruded-extruded joint samples the weld bead thickness remains approximately the same even with a change in the welding parameters. The values of weld bead height however remains almost the same for both types of samples (extruded-extruded & extruded-injection molded) showing a zero slope. ASTM F2620-06 defines that for proper fusion weld PE joints the thickness of the weld beads will be approximately 2-2 ½ times the bead height [15]. Comparing the obtained values of weld bead sizes as plotted in Figures 6, 7, 8 and 9 against the definition of ASTM F2620-06 regarding a proper fusion weld, it is observed that all the welds made between extruded-extruded samples fulfill this criteria. The resulting weld bead thickness of the weld beads for extruded-extruded samples is greater than 2 times the bead height. However for few joints made between extruded-injection molded samples the weld bead thickness is less than 2 times of the bead height and these joints are termed as improper weld joints [ASTM F2620-06]. Estimating the joint quality on the basis of weld bead sizes as suggested by ASTM F2620-06 show that all the joints are of good quality having no major influence of weld parameters.

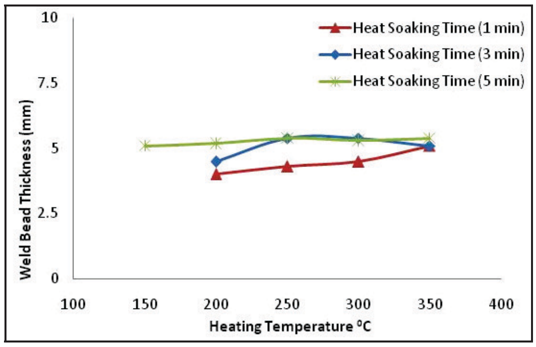


Figure 8: Effect on weld bead thickness (extruded – extruded joint)

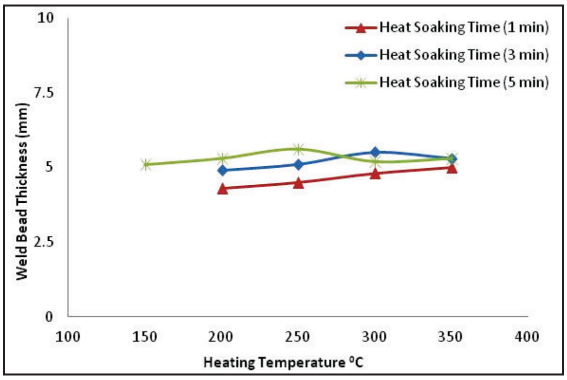


Figure 9: Effect on weld bead thickness (extruded – injection molded joint)

3.3 Effects on Tensile strength and Elongation of Joints

Studies have shown that tensile energy to break (TEB) and maximum strain observed during tensile test of a fusion joint are considered the most acceptable parameters for distinguishing between joints of different qualities [2, 15]. Since the thickness of weld beads for all the fusion joints made is approximately two times the bead height, based on the hypothesis suggested by ASTM F2620-06, the values of tensile energy to break (TEB) and maximum strain shall be identical for all these weld samples. For such comparison the values of tensile strength and total elongation at fracture obtained trough experimentation are plotted in Figure 10-13. Figure shows that tensile strength changes like a bell curve with changing weld parameters. The behavior is almost identical for both types of weld samples (extruded-extruded and extruded-injection molded), however the resulting values of tensile strength are not the same for both sample types. From the plots of Figure 10, 11, 12 and 13, it is observed that the values of tensile strength do not change significantly for heat soaking time of 3 & 5 minutes at corresponding heating temperatures. This observation holds valid for both type of fusion joints (extruded-extruded and extruded-injection molded). On the other hand for heat soaking times less than 3 minutes the fusion weld results in a poor quality of joints having lower structural strengths. The reduction in tensile strength is because of improper heating of joining surfaces that consequently result in lack of fusion. Although the joints made at high heating temperatures exhibit considerably good structural strength, the resulting weld beads show signs of burning of the HDPE material. The same observation is also evident from the results of microscopic examination as presented in Figure 14. The plots presented in Figure 10, 11, 12 and 13 show that maximum strength and percentage elongation at fracture for both type of weld joints (extruded-extruded and extruded-injection molded) is obtained at heating temperature of 250^{0}C for a heat soaking time of 3 minutes. The resulting values of tensile strength for extruded-extruded fusion joints are comparably high as compared to the tensile strength of extruded-injection molded fusion weld samples. However the values of percentage elongation at fracture remains almost identical against the maximum tensile strength values obtained with changing weld parameters.

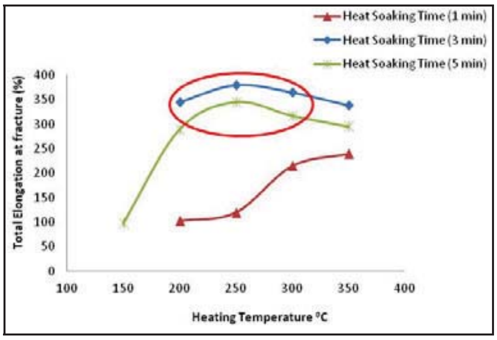


Figure 10: Effect of weld parameters on percentage elongation (extruded – extruded joint)

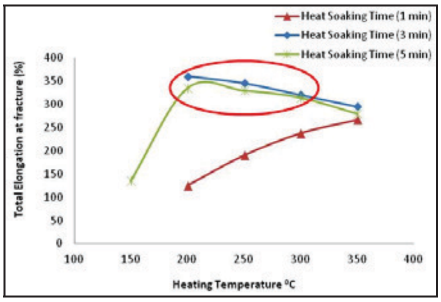


Figure 11: Effect of weld parameters on percentage elongation (extruded – injection molded joint)

Comparing the tensile strength values obtained for both types of fusion joints (extruded-extruded & extruded-injection molded) against the parent HDPE material, it is observed that extruded-extruded fusion welds exhibit less reduction in tensile strength. Figure 12 and 13 show percentage reduction in tensile strength for both types of fusion welds. The reduction in tensile strength is due to stress concentration at the joining line and residual stresses induced in the heat affected zone (HAZ) while heating of joining surfaces. It is because of this stress concentration that all the tensile samples fail near the weld joint.

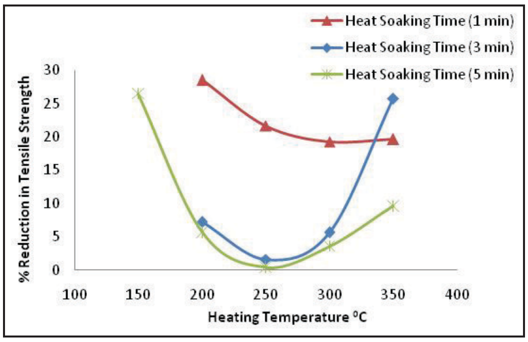


Figure 12: Percentage reduction of tensile strength (extruded – extruded joint)

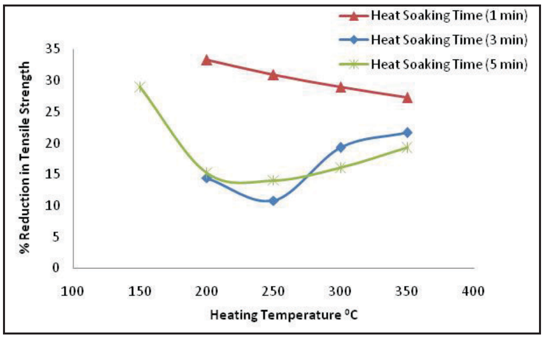
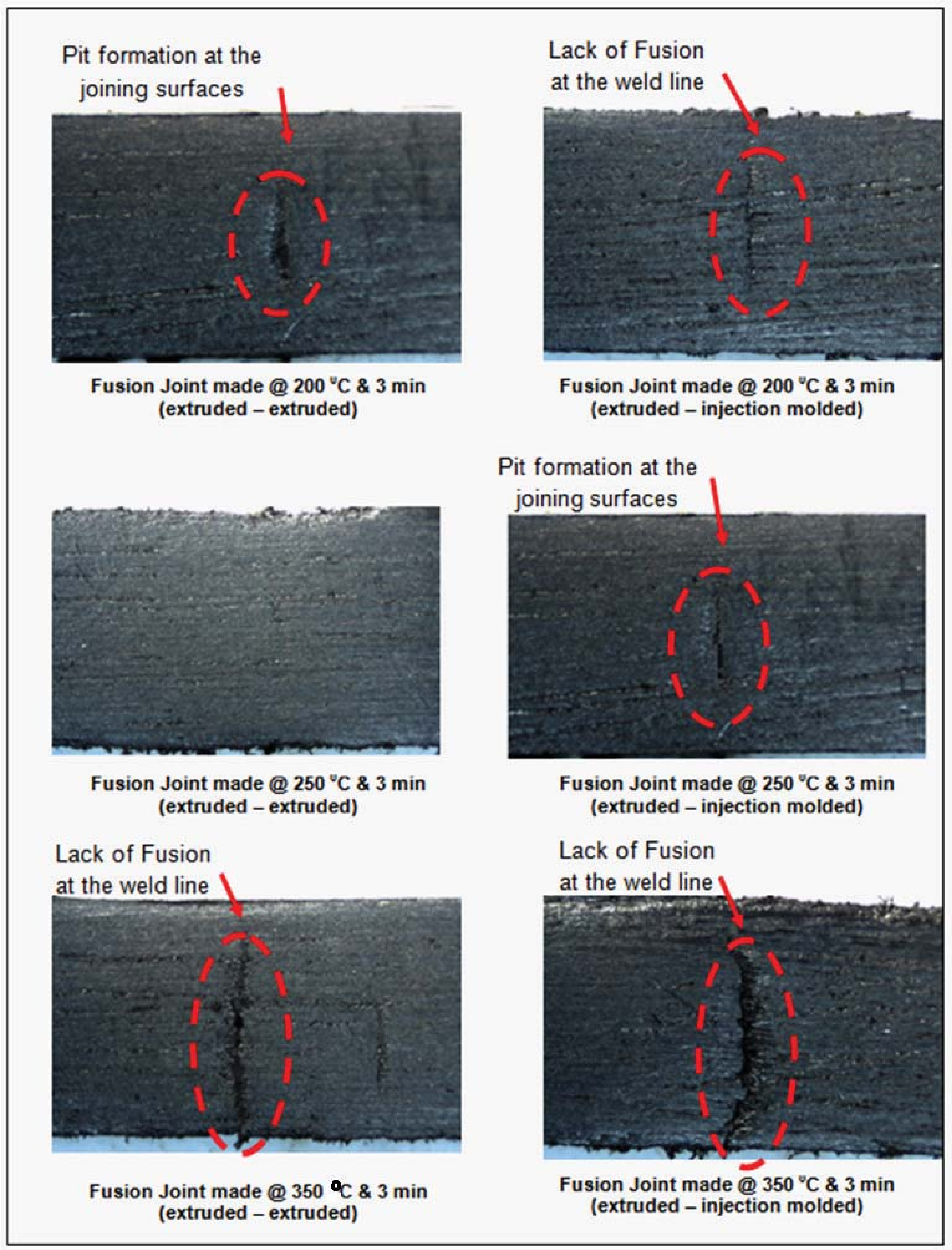


Figure 13: Percentage reduction of tensile strength (extruded – injection molded joint)

Based on present research it is now known that joint strength for HDPE material is weakest between extruded and injection molded weld samples, this value of tensile strength can serve as a failure criteria while designing any HDPE installation involving fittings or connections. During this research work, microscopic examination of the weld surfaces is also carried out. The images of the joint section are obtained using microscope at 10 x sizes and presented in Figure 14. It is evident from the microscopic images that extruded – injection molded weld samples show an increased lack of fusion as compared to extruded – extruded weld samples. It is because of this lack of fusion that the structural performance of extruded-injection molded joint samples is lower than extruded-extruded joint samples for same welding parameters.



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igure 14: Microscopic view of fusion welded surfaces (extruded - extruded & extruded - injection molded joints)

4. Conclusion

Based on the research work it is now known that structural performance of fusion welds made between extruded and injection molded HDPE samples is affected by changing the weld parameters. The tensile strength of the extruded-injection molded HDPE joint samples is approximately 12% less than the strength of extruded-extruded HDPE joint samples. This reduction in tensile strength is more for fusion joints that are made using improper fusion weld parameters. Hence, using the tensile strength of extruded-extruded HDPE samples for all the applications may lead to design failure. Applications such as type IV composite CNG cylinder having fusion joints between extruded-injection molded HDPE materials are critical in the sense that they need precise test data to accurately model/predict its behavior. However it is also evident from the present research that the optimum weld parameters for extruded-extruded HDPE samples and extruded-injection molded HDPE samples are nearly the same with the prior resulting in better structural performance than the other.

An extension to the present work is studying performance of fusion joints made between extruded and injection molded HDPE samples under cyclic loading. Further to this the results can be compared against fatigue life of extruded-extruded HDPE joint samples.

5. References

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