



**MECHANICAL PERFORMANCE OF ELECTRO FUSION
AND BUTT FUSION WELDING OF HIGH DENSITY
POLYETHYLENE PIPES**

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ABSTRACT

Electro fusion welding and butt fusion welding are common methods for joining polyethylene pipes used for water and gas distribution. Because of the wide use of these two methods in infrastructure engineering projects, this study was examined welded pipe joints and pipe materials with the intent of reducing errors in infrastructure projects.

The purpose of this study is to increase the knowledge and to examine these two aspects of the electro fusion and butt fusion welding methods to establish which one of them as the best performance for a specific engineering service project.

Tensile tests, tensile tests of strip (uncracked and cracked samples) and hydrostatic pressure tests are performed on the un-welded pipe and welded pipe (Electro fusion and butt fusion welding). These two methods are important to test, study on pipe and then joining to get the best quality in infrastructure projects. Additionally, it was achieved numerical analysis of the experimental results by employing the *ANSYS* program for tensile test samples.

Keywords: High Density Polyethylene, Electro Fusion Welding, Butt Fusion Welding, Tensile Test, Hydrostatic Pressure Test.

ÖZET

ELEKTRO FÜZYON VE ALIN KAYNAKLI YÜKSEK YOĞUNLUKLU POLİETİLEN BORULARIN MEKANİK PERFORMANSI

Elektro füzyon ve alın kaynağı, su ve gaz dağıtımındaki boruların birleştirilmesi amacıyla kullanılan genel metotlardır. Altyapı mühendislik projelerinde bu iki metodun geniş uygulama alanları olması sebebiyle üretim hatalarını azaltmak için çalışmada kaynak yapılmış boru bağlantıları ve malzemeleri incelenmiştir.

Bu çalışmanın amacı; elektro füzyon ve alın kaynağı metotlarını araştırmak, özel mühendislik servis projeleri için hangisinin daha iyi performans gösterdiği ile ilgili yorum yapmak ve bilgiyi artırmaktır.

Deneyle; boruların standartlara göre yapılmış çekme testleri, çatlaklı ve çatlaksız levha çekme testleri ile kaynaklı ve kaynaklız hidrostatik basınç testlerini içerir. Altyapı projelerinde en iyi kalitede bağlantı yapmak amacıyla boruları ve bağlantılarını test etmek için elektro füzyon ve alın kaynağı yöntemi önemlidir. Deneysel çalışmalara ek olarak standart çekme test numuneleri için ANSYS programı ile deneysel sonuçların sayısal analizi gerçekleştirilmiştir.

Anahtar Kelimeler: Yüksek Yoğunluklu Polietilen, Elektro Füzyon Kaynağı, Alın Kaynağı, Çekme Testi, Hidrostatik Basınç Testi.

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LIST OF SYMBOLS

C :	Carbon
dn :	Nominal outside diameter
e_{min} :	Minimum wall thickness
e_n :	Nominal wall thickness
GPa :	Giga Pascal
H :	Hydrogen
mm :	Millimeter
MPa :	Mega Pascal
N :	Nitrogen
P :	Pressure
Si :	Silicon
S:	Thickness
s:	Second
t :	Time
σ :	Hoop Stress

LIST OF ABBREVIATIONS

BFW:	Butt Fusion Welding
CT:	Cooling Time
DVS:	Deutscher Verlag für Schweißtechnik
EFW:	Electro Fusion Welding
HDPE:	High Density Polyethylene Pipe
ISO:	International Organization for Standardization
LDPE:	Low Density Polyethylene
LLDPE:	Linear Low Density Polyethylene
MDPE:	Medium Density Polyethylene Pipe
OD:	Outer Diameter
PC:	Polycarbonate
PE:	Polyethylene Pipe
PEX:	Cross Linke Polyethylene
PN:	Pressure Nominal Of Pipe
PP:	Polypropylene
PS:	Polystyrene
PTFE:	Polytetra Fluoro Ethylene
PVC:	Poly Vinyl Chloride
RC:	Resistance Crack
SC:	stress corrosion
SCG:	Slow Crack Growth
SDR:	Standard Diameter Ratio
UHMWPE:	Ultra-High Molecular Weight Polyethylene
3D:	Three Dimension

1. INTRODUCTION

Solid materials have been conveniently grouped into three basic classifications: metals, ceramics, and polymers. This scheme is based primarily on chemical makeup and atomic structure.

Most materials fall into one distinct grouping or another although there are some intermediates. In addition, there are composites, combinations of two or more of the above three basic material classes. A brief explanation of these material types and representative characteristics is offered next another classification is advanced materials those used in high-technology applications mean semiconductors, biomaterials, smart materials and nano engineering materials [1].

Polymers incorporate the well known plastic and elastic materials. A large portion of them are natural exacerbrates that are artificially in light of carbon, hydrogen and other nonmetallic components (mean O, N, and Si). Besides, they have vast sub-atomic structures frequently chain-like in nature that have a spine of carbon iotas. A portion of the basic and natural polymers are polyethylene (PE), nylon, poly vinyl chloride (PVC), polycarbonate (PC), polystyrene (PS), and silicone elastic.

These materials normally have low densities while their mechanical attributes are by and large unlike the metallic and artistic materials. They are not as hardened not as solid as these other material sorts. However on the premise of their low densities commonly their solidness' and qualities on a for every mass premise are equivalent to the metals and pottery [2].

In addition many of the polymers are extremely ductile and flexible (i.e., plastic), which means they are easily formed into complex shapes. In general, they are relatively inert chemically and unreactive in a large number of environments. One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances limits their use. Furthermore, they have low electrical conductivities and they nonmagnetic materials [3].

PE is a standout amongst the most well known polymeric materials because of its favorable circumstances, for example, cost viability, exceptionally stable concoction structure, great mechanical properties and moderately simple procedure for items. Among the different building applications, this material has been generally decided for underground pipe frameworks for sewage. In the sewage channel framework, different basic imperfections might be created by development procedures and deficiency of support

subsequently, sewage spillage happens, and thwarts the consistent sewage transfer prepare and defiles the earth, in the long run prompting natural contamination. Once the spillage is recognized up and coming in situ repair is basic to avoid further harm [4].

PE pipes have been widely used for gas and water distribution piping over the last 50 years, due to the ease of installation, long-term service durability and cost-effectiveness [5].

PE have some types as Low Density Polyethylene (LDPE) has been widely used in many fields due to its excellent properties, such as electrical insulation, chemical corrosion resistance, high machinability and so on [6].

High Density Polyethylene (HDPE) is a material widely used for the distribution of drinking water pipes are subjected to an internal pressure due to the water flow [7].

HDPE is more unbending and harder than PE. Its rigidity is four times that of LDPE and its compressive quality is three times better PE is solid, greatly intense and exceptionally strong. Whether it is searching for long administration, inconvenience free establishment, adaptability, imperviousness to chemicals, HDPE will meet every one of it necessities[8].

HDPE is one of the most astounding effect safe thermoplastics accessible and keeps up brilliant machinability and self-greasing up qualities. Properties are kept up even at greatly low temperatures. HDPE has great compound resistance of corrosives and in addition stress splitting resistance (except for solid oxidizing acids at lifted temperatures). Certain hydrocarbons cause just a light surface swelling at moderate temperature. HDPE channels can convey consumable water, wastewater, slurries, chemicals, risky squanders, and packed gasses [8].

PE 100 RC polyethylene minimum strength required 10 MPa resistances to crack. This is a term that was developed in Europe to designate PE 100 materials that have even higher slow crack growth (SCG) resistance than PE 100+. The “RC” refers to “resistance to cracking.”

These PE 100 RC materials are used in especially demanding applications where a very high level of SCG resistance is required. One such application is for gas companies to use the natural backfill when installing PE 100 RC pipe in rocky areas, and avoid the cost of importing sand backfill. Their very high resistance to SCG are prevents any rock impingement failures [9].

In the past decades, the use of polymeric engineering materials in civil

infrastructures and environmental engineering projects has steadily increased .

At the same time, commercial household products made from plastics have also greatly increased because of their economical manufacturing, light weight and chemical resistance [10].

Medium density polyethylene (MDPE) is commonly used in various engineering applications. Specifically, they are widely using in agricultural water irrigation and distribution systems as well as for underground sewerage pipes and different way of pipe [11].

Water and natural gas projects have a very important factor which have direct relation to the quality of service project is the joining of connection PE pipes which have important play in this process.

A fundamental part of any pipe framework is the technique used to join the framework segments. Legitimate building configuration of a framework are contemplated the sort and adequacy of the systems used to join the pipe segments and appurtenances, and also the sturdiness of the subsequent joints. The uprightness and flexibility of the joining procedures utilized for PE pipe permit the architect to exploit the execution advantages of PE in a wide assortment of utilizations [12].

For joining polymer pipes used in water and gas projects have many types as mechanical and fusion, solving and explain the factor and performance of joining too necessary.

Mechanical fittings typically have a body that is a pressure-containing component that fits over the outside diameter of the pipe, a threaded compression nut or follower gland with bolting arrangement, and elastomeric seal rings or gaskets. Fittings that provide resistance to pipe pullout will also have some type of gripping device to prevent the pipe from pulling out of the fitting. All mechanical compression fittings apply a compressive load on the pipe to create a pressure seal or activate the restraint device.

Most manufacturers of these couplings recommend the use of insert stiffeners to reinforce the pipe against outer diameter (OD) compression from the coupling. Manufacturer's recommended procedures should be consulted for specific information. The pipe stiffener is positioned in the pipe bore so that its location is under the gasket and the gripping device (if applicable) of the fitting. The stiffener keeps the pipe from collapsing from the compression loads, which could result in leakage or even failure of the restraining feature if the fitting provides restraint [13].

Most of the times mechanical fittings are using in the processes for connecting two different material pipes for example PE pipe with steel pipe because two different types of pipes are very complex in welding process.

Welding methods applied on polymer materials two important methods which employed in water and gas network projects. Butt and electro fusion welding methods are widely used for joining pipe welding methods to join of natural gas and water pipes.

Because of the Electro fusion welding and the butt fusion welding are the main two welding technology in influence directly to the safety and quality of welding explain about it [14].

Butt Fusion welding (BFW) technique is usually used to join PE parts together to shape a system of pipelines for the development or recovery of covered foundation, for example, water metropolitan primary system, sewers and gas pipelines. BFW procedure is utilized widely to associate a few PE pipeline parts welding administration with all welding stages and the progressions of the weight and temperature and time [15].

Electro Fusion welding (EFW) joint incorporate proper outline parameters (structure and welding methods), well establishment, precise examination, and reasonable evaluation. Among the above issues, the configuration parameters have pulled in many considerations. Looked into the EFW procedure and separated it into four periods as indicated by the development methodology of the holding quality between EFW fitting and pipes, the influence of welding voltage, welding time, freedom amongst funnels, and fitting to the mechanical properties of EFW joint.

2. LITERATURE SURVEY

This chapter represents the survey of literature relevant to the present thesis topic which includes the experimental, numerical analysis and modeling about the PE pipes and it is joining.

Jakub. M [16] focused on numerical modeling of the quasi-brittle failure which is a direct result of slow creep crack growth. Welding of polyolefin pipes causes material inhomogeneity in the welded region and the weld bead shape introduces geometric stress raisers. The results of numerical modeling are presented for a polyethylene pipe (PE 100 110 x 6.3 SDR 17.6). Polymer is standout amongst the most widely recognized materials utilized in industry pipe line, but the results of the thesis can be used for any other polyolefin material as well.

Vesely. P et al [17] examined two condition of the welded channel framework are compared, one considering the ideal weld dot geometry and the other one considering the geometry in expelling the weld bead once the welding procedure is done. In both cases the inhomogeneous dissemination of material properties inside the welded locale is considered. The outcomes demonstrate that the weld may negatively affect the lifetime particularly when the weld bead is removed.

Khonakdara et al. [18] reported the effect of electron beam irradiation on cross-link PE and crystalline structure of low-and HD polyethylene. In their study, the crystallization conduct was confined after a progression of cooling and warming the illuminated examples because of decline the length of chain portion required for common crystallization by chain folding through the arrangement of cross-link joints.

Seok. H et al [19] investigated the fusion and tensile tests were performed after the electrofusion joint was made in the polyethylene pipe using carbon fiber. The results showed that the fusion time was shorter and the temperature inside the pipe was higher with an increase in the current value. The ultimate tensile strength of specimens was higher than that of virgin polyethylene pipe, except for polyethylene pipes joined using a current of 0.8 A. The best fusion current value was 0.9 or 1.0 A because of the short fusion time and lack of transformation inside the pipe. Thus, it was shown that carbon fiber can be used to replace the copper heating wire.

Tariq, et al [20] talked about disappointment examination directed on HDPE which goes about as the liner of composite packs regular gas cylinder. Spillage from the barrel

was seen after around 2000 cycles of hydrostatic weight testing at 250 bars. Visual investigation uncovered that the spillage happened from the circumferential combination joint between the barrel and arch segment. The chamber and arch segments were delivered from various strategies and joined together by utilizing a BFW procedure directed by a neighborhood producer. The examination was done utilizing different systems including mechanical, warm and metallurgical examination. Fractography of the fizzled joint surface indicated stepwise stamps regular of a weariness disappointment. Mechanical testing results demonstrated that the quality of vault area was essentially lower than that of the chamber segment.

Riahi, et al. [21] investigated all parameters having impact on quality of EFW of PE pipes were reviewed. Among those outstanding points recognized, one has been carefully and selectively studied. Impact of clearance among the coupler and pipes and its effect on the resistance of EF weldment at such a location had been chosen for analysis. Obtained results from modeling of finite element of EF coupler in ANSYS have been compared with the real experiments. In finally, obtained result of increased in clearance, peak pressure decreased and in attempting to reach the peak, by prolonging the heating time, weld pressure decreases.

Elbagory, et al. [22] carried out the fracture toughness of HDPE was fundamentally affected by the crosshead speed, and additionally the nearness of a butt weld. In view of the testing perform as a major aspect of this study, the take after conclusion be drawn, For welded and un welded examples, the obvious break durability increments as the crosshead speed increments at the same the proportion between example thickness to width proportion.

Lai, et al. [23] investigated MDPE pipes were increasingly used in the gas industry; welding defects were becoming a safety concern. In this study, BFW welded of MDPE pipe joints with spherical and planar defects of various sizes were studied by experimental tensile tests and finite element analysis. These defects were considered for simulating lack of bonding during the welding. The tensile test results showed that pipe strength was not reduced by defects that were up to 15% of the pipe's thickness in size. Finite element analysis verified that the effects of steel defects inserted intentionally before welding are comparable to those of air defects.

Starostin and Ammosova. [24] carried out the thermal processes in BFW of PE pipe at low ambient temperatures were get on the basis of mathematical simulation of the thermal process, have proposed and verified a method of determining the melting time when PE pipe is welded at below-standard ambient temperatures. A method had been outlined for calculating the non-steady wall-temperature field in welding polymer pipe, taking account of the latent heat of phase transition and the thermal influence of burring. The determination of appropriate dimensions for the heat-insulation chamber in the cooling stage had been described. After successful testing, the proposed methods may be used to determine the parameters corresponding to permissible temperature field dynamics in welding PE pipe when the ambient temperature was below the standard range.

Sevcik, et al. [25] solved a three-dimensional model of a pressurized PE with a weld was made so as to gauge the anxiety stress concentration effect for a crack situated inside the weld. A correlation with qualities acquired for an edge-crack tension sample, normally utilized for a trial determination of weld properties, is performed. The contrast between the stress concentration variable in a homogeneous funnel and the outcomes considering the adjustments in material properties inside the weld was displayed. A traditionalist and effortlessly material relationship for computing the stress concentration variable in a funnel weld is proposed.

Riahi, et al [26] investigated, while the fundamental goal was to decrease the last globule's size of the weld, 9 distinctive examinations with various heat and pressure load and equivalent timing for every heat stage were characterized. Numerical demonstrating of FEM of the heating procedure was done in the PC programming considering administering physical conditions in the weld to decide heat conveyance and in addition essential dot geometry. Along these lines, the model was contrasted and results from experimentations. Cross-cut of the shaped essential dots toward the end of the warming procedure were arranged and contrasted and comes about because of the model.

Leskovics, et al [27] inspected to un welded PE tube. X-beam diffraction, differential checking calorimeter and Fourier transform infrared spectrometer estimations uncovered points of interest of of axial amorphous and crystal orientation in the origin pipe. As opposed to desires considering the press stream nature of BW, arrangement of haphazardly situated precious crystal structure was resolved in the weld zone. Malleable and indented sway tests at encompassing and sub-surrounding temperatures and differing

rates of effect demonstrated that welding reduced strength to failure. Microscop assessment of the brittle failure surfaces uncovered the surface morphology of the welded zone to be coarser than the non-welded PE material.

Jianfeng, et al [28] investigated defects may extraordinarily decrease the mechanical performance of the EFW joints and risk well being running of the pipeline system. To assess danger of these imperfections and give an essential comprehension to the failure system of EF joints, a far reaching study on defects and failure way was led in under pressue. Test results demonstrate that there are three principle failure method of EF joint under internal pressure that was cracks through the combination interface, through the fitting, and through copper wire interface.

Fangjuan, et al [29] investigated shows that one of the failure modes of HDPE pipe is the crack slowly grows across the thick direction and leads to failure at last, so that it is very important to study the resistance to crack initiation of HDPE pipe and its butt-fusion welded joint. In this study, the elastic-plastic fracture mechanics parameter, crack opening displacement is used to describe the fracture initiation behaviors for the HDPE materials and its BFW joints. The results show that saturation initial crack of HDPE pipe materials and BFW joints decreases with the decreasing temperature.

Kamaya. [30] discussed procedure for estimating true stress strain curves of the good type was proposed. Only the yield and ultimate strengths are required for the estimation. The estimation method was added to eight materials with a specific end goal to examine legitimacy of estimations for surveying basic trustworthiness of crack HDPE. It was demonstrated that the adjustment in disappointment load determined utilizing the assessed stress strain bends expanded as the yield quality was decreased. It was reasoned that the adjustment in failure force derived utilizing the proposed system could be constrained to fewer than 5%.

Nie, et al. [31] carried out experiments and then the results showed that when the die rotated during the extrusion process of PE pipes, the hoop stress exerted on the polymer melt could make the molecular orientation deviate from the axial direction, and therefore the consequent multi-axial orientation of molecular chains could be obtained. As a result, the PE pipe with better resistance to SCG was prepared. Compared to the PE pipe produced

by the conventional extrusion, the crack initiation time of the PE pipe manufactured by the novel method increased from 27 to 57 h.

Pinter, et al [32] described the main elements of a novel concept for lifetime and safety assessment of PE pressure tube for arbitrary installation state based on modern methods of fracture mechanics. At the core of the proposed concept is the accelerated generation of so called synthetic crack growth curves and corresponding material laws for crack growth initiation and slow crack growth for service-near temperature conditions without the use of stress cracking liquids.

Choi, et al. [33] discussed a deterministic modeling of slow (SC) crack growth process is developed using Crack Layer theory. Numerical solution of SC crack growth equations is discussed. Comparison of the kinetics of cracks driven by SC and by stress only is presented. Conventional plot of SC crack growth rate vs. the stress intensity factor is constructed and analyzed. An algorithm for conservative estimation of lifetime of engineering thermoplastic subject to a combination of mechanical stresses and chemically aggressive environment is discussed.

Peres, et al. [34] investigated the concept of 'regression curve, i.e. of a time-to-failure criteria based in long-term hydrostatic strength tests, is criticized and concluded to be unsatisfactory for this purpose. An alternative approach is suggested, which is based on shorter-term tests. This is delineated by testing five HDPE are intended for funnel expulsion and contrasting and their standard 'relapse bends'. The get results are predictable with the 'relapse bend'- based investigation, legitimizing the utilization of the option approach in the business.

Stashchuk and Dorosh [35] analyzed the papers dealing with one-piece polymeric (flexible) pipes operating under the action of soils. The factors and criteria being most important for applications in the engineering calculations and design of cellular pipes are determined.

Lee, et al. [36] investigated the results of the stiffness and flattening tests showed that there were no big differences between the joints made from these two plates. In the leakage test, however, the pipes welded with the conventional heat plate leaked below the required test conditions, while the pipes welded with the grooved heat plate did not show any leakage, even in a range higher than the required conditions. The tensile and bending

strength were also improved. The results demonstrated that the grooved heat plate accomplished more complete fusion at the pipe joints and induced high quality joints.

Boot, et al. [37] researched the execution of linings introduced utilizing the two most well-known pipe grade of polyethylene (PE80 and PE100) is then examined under both short term and creeping stacking conditions. This is accomplished utilizing a mix of research center testing systems together with two and three-dimensional finite element model. The conceivable effect of longitudinal crack actuated by the establishment forms on crossing limit is incorporated into the examination. Express outline proposals for the criteria considered are acquired.

The focus of this study is the life span for water and gas pipe networks which depend on the mechanical performance of joining the PE pipes, which has direct impact on the cost of the project and community health. Therefore, this thesis achieved the tensile tests and internal pressure testing on the HDPE pipes both un welded and welded (BFW and EFW).

The BFW method is now in use, the BFW does not need any parts which means it is more economic than the EFW, but the EFW is new method for using by generally, the EFW need a coupler for joining which contains a metal wire for melting the coupler and the wall pipe to mixing by permanent joint.

The experimental work involved a tensile test of un welded, BFW and EFW, tensile strips for cracked and uncracked sample of un welded, BFW and EFW. and a hydrostatic pressure test of un welded, BFW and EFW.

EFW and BFW were performed all stage of experiments for getting the results and to compare the experimentally data with the numerical analysis of of tensile test samples.

Then evaluating of all data offers better working in information field for the engineering designers and the supervisor of projects with the goal of quality for these engineering projects.

3. MATERIALS

Materials have been two mainly grouped into two fundamental types: metals and non-metals, then nonmetals have two main classifications as polymer and ceramics which showed as in Figure 3.1. This scheme is constructing essentially in light of chemical makeup and nucleus structure.

Most materials fall into some particular gathering in spite of the fact that there are a few intermediates. Likewise, there are the composites, mixes of two or a greater amount of the above three fundamental material classes. A brief explanation of these material types and chemical makeup is offered next another types is advanced materials those utilized as a part of high-innovation applications mean semiconductors, biomaterials, smart materials and nano engineering materials.

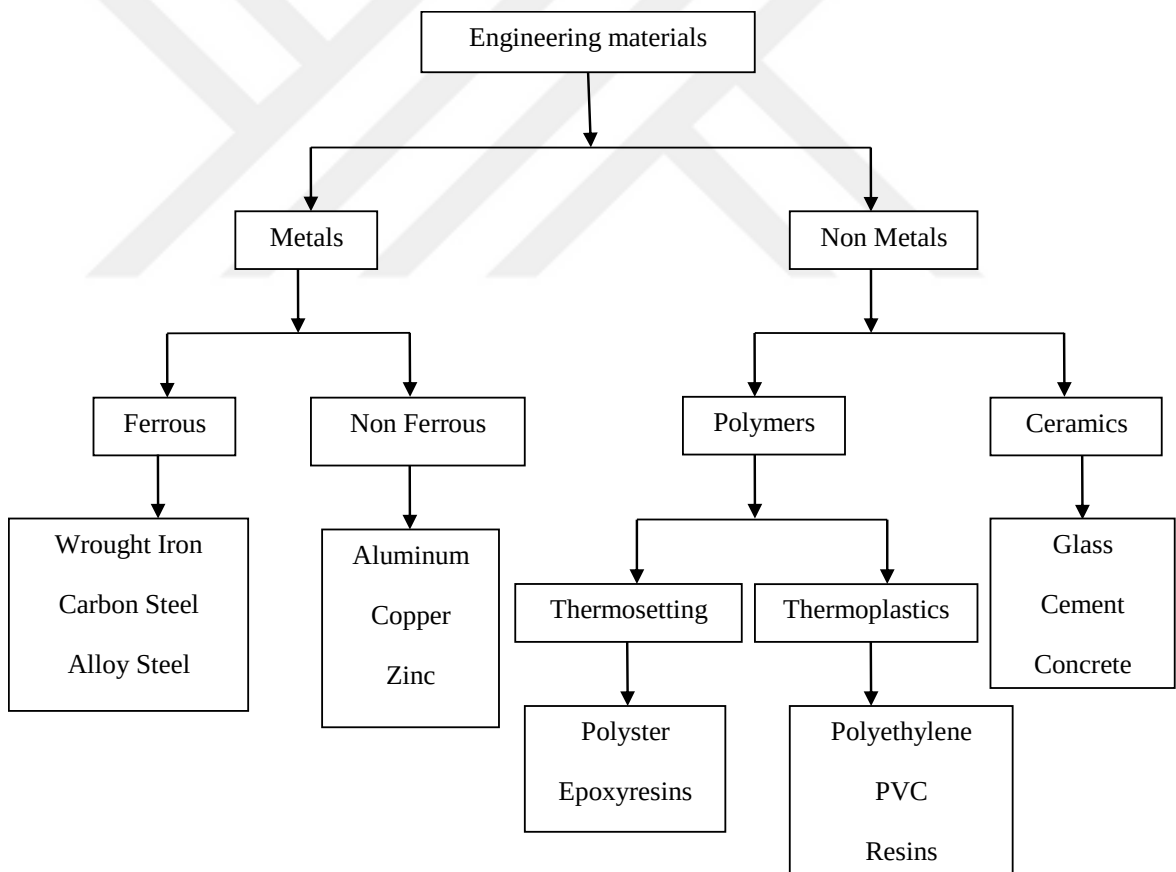


Figure 3.1. Classification of engineering materials [1].

3.1. Metals

Metals are chief, basic substances able of changing their form forever. They are good guides of heat and electrics. These may be of ferrous or non-ferrous letters used for printing. The behavior and properties of ferrous metals are dependent on the rate on a hundred and the form (phase and components) of carbon present in them [38].

3.2. Nonmetals

Nonmetals are chemical elements that mostly lacks metallic attributes. Physically, nonmetals tend to be highly volatile (easily vaporized), have low elasticity, and are good insulators of heat and electricity; chemically, they tend to have high ionization energy and electronegativity values and gain or share electrons when they react with other elements or compounds. Seventeen elements are generally classified as nonmetals; most are gases (hydrogen, helium, nitrogen, oxygen, fluorine, neon, chlorine, argon, krypton, xenon and radon); one is a liquid (bromine); and a few are solids (carbon, phosphorus, sulfur, selenium, and iodine) and it is classified for two mainly types as ceramics and polymers [39].

3.2.1. Ceramics

A ceramic is an inorganic, nonmetallic solid material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds. The crystallinity of clay materials reaches from exceedingly arranged to semi-crystalline, and regularly totally shapeless (e.g., glasses). Fluctuating crystallinity and electron utilization in the ionic and covalent bonds cause most artistic materials to be great warm and electrical protectors and widely scrutinized in clay designing. All things considered, with such a substantial scope of conceivable choices for the arrangement/structure of a fired (e.g. about the greater part of the components, almost a wide range of holding, and all levels of crystallinity), the expansiveness of the subject is immeasurable, and identifiable characteristics (e.g. hardness, durability, electrical conductivity, and so on) are difficult to determine for the gathering in general. Notwithstanding, consensuses, for example, high dissolving temperature, high hardness, and poor conductivity, high moduli of flexibility, substance resistance and low malleability are the standard, with known exemptions to each of these guidelines (e.g. piezoelectric earthenware production, glass move temperature,

superconductive pottery, and so on.). Numerous composites, for example, fiberglass and carbon fiber, while containing earthenware materials, are not thought to be a piece of the clay family [40].

3.2.2. Polymers

The word polymer is derived from the classical Greek words poly meaning “many” and meres meaning “parts.” Simply stated, a polymer is a long-chain molecule that is composed of a large number of repeating units of identical structure.

Polymers are by and large non-crystalline solids. Their mechanical properties are very delicate to sub-atomic arrangement, level of polymerization and cross-connecting. Connecting of an ethylene monomer (C_2H_4) to shape polyethylene ($(C_2H_4)_n$) is appeared in Figure 3.2. Two single bonds (C–C) in polymer are shaped from every twofold bond ($C=C$) in the monomer. Polymers are for the most part produced using carbon mixes however can likewise be produced using inorganic silicates and silicon.

They are likewise found in characteristic frame a portion of the common and engineering polymers are assembled as specific polymers, for example, proteins, cellulose, and silk, are found in nature, while numerous others, including polystyrene, polyethylene, and nylon, are delivered just by manufactured courses. At times, normally happening polymers can likewise be delivered artificially. A vital illustration is characteristic elastic, known as polyisoprene in its engineered structure.

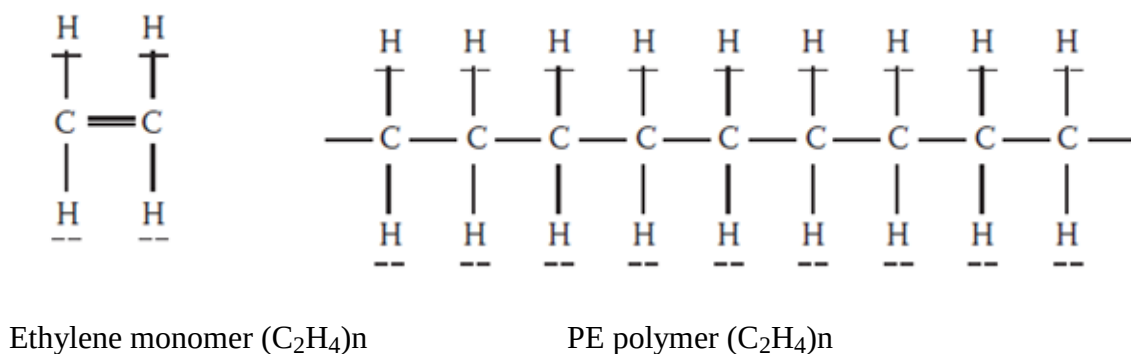


Figure 3.2. Ethylene monomer and polyethylene polymer [41].

Polymers that are able to do high augmentation under encompassing conditions find essential applications as elastomers. Not with standing common elastic, there are a few critical engineering elastomers including nitrile and butyl elastic [41]. A considerable lot of

them are natural aggravates that are artificially in view of carbon, hydrogen and other nonmetallic components (mean O, N, and Si). Moreover, they have vast sub-atomic structures frequently chain-like in nature that have a spine of carbon iotas .

They are strong materials that contain one or more polymeric substances which can be formed by stream. Polymers, the fundamental element of plastics, make an expansive class out of materials that incorporate normal and engineering polymers. Nearly all plastics are made from the latter. In commercial practice, polymers are frequently designated as resins and the classifications of the polymers are thermoplastics, thermosets and elastomer [42].

3.2.2. a. Thermosetting Plastics

They have a 3D system of essential bonds in every one of the headings as in Figure 3.3. These kind of plastics, on utilization of warmth, first turn out to be delicate and afterward hard, and after that, they can't be diminished again by use of warmth. This perpetual solidifying called curing is a compound change. Regular cases of thermosets are phenolic, epoxies as (air ship segments, tooling dances and installations, coatings, cements for autos), melamine as (cements, coatings, overlays, dinnerware, electrical segments, handles, family unit things, development material, furniture-production), bakelite as (accuracy made parts, vehicle circle brake barrels, handles, plastic product, electrical items and protection, attachments and attachments, car parts, light backings.

They by and large require both warmth and weight to be formed into any shape. On the off chance that strongly warmed, they separate by corruption. Critical sorts of thermosetting plastics demonstrating their properties and applications are showed in Table 3.1. which peak to the properties and use of thermosetting plastics.



Figure 3.3. Thermosetting plastics [41].

3.2.2. b. Thermoplastics

Their long-chain molecules are secondary bonded as in Figure 3.4. Which break more readily due to increase in thermal energy. They become soft when elated (generally with pressure) but require cooling to set into a definite shape. Since no chemical hardening action takes place, the shaped articles resoften on reheating.

Just a physical change is included with them. They have incredible versatility yet low dissolving point. Regular illustrations are cellulose, polystyrene, polyvinyl chloride (PVC), nylon, Teflon, polysulphone, polyurethane, acrylic and acetyl. Essential thermoplastics are appeared in Table 3.2 portraying their properties and applications [43].

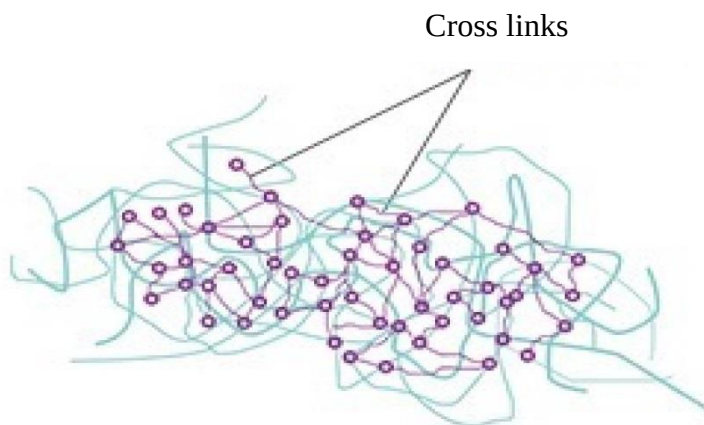


Figure 3.4. Thermoplastics [43].

3.2.2.c. Elastomers (Rubbers)

Organic polymeric materials, which, at room temperature, can be extended over and over to twice their own particular length (elongation be 100%, endless supply of anxiety, will come back with power to the first length. Elastomers might be thermoplastic (reversible warmth softening) or thermosetting (irreversible compound change) as in Figure 3.5.

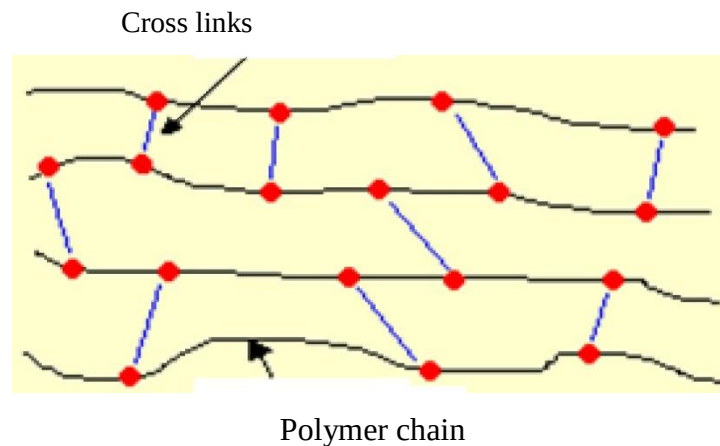


Figure 3.5. Structure diagram of elastomer [43].

These materials commonly have low densities while their mechanical attributes are for the most part not at all like the metallic and artistic materials. They are not as firm not as solid as these other material sorts. However on the premise of their low densities commonly their solidness and qualities on a for every mass premise are tantamount to the metals and earthenware production [44].

More a considerable lot of the polymers are greatly bendable and adaptable (i.e., plastic), which implies they are effortlessly framed into complex shapes. By and large, they are generally inactive artificially and inert in countless. One noteworthy disadvantage to the polymers is their inclination to diminish and/or decay at unassuming temperatures, which, in a few occasions constraints their utilization. Besides, they have low electrical conductivities are nonmagnetic.

Table 3.1. Properties and applications of thermosets [43].

Properties	Polyester	Epoxy	Phenolic	Silicone
Specific gravity	1.2	1.2	1.2	1.3
Normal usable temperature (°C)	80-180	90-120	250-300	250-300
Molding pressure	Low to medium	Low to medium	Low to high	Low to medium
Mechanical properties	Very good	Very good	Very good	Fair
Electrical properties	Excellent	Excellent	Good	Excellent
Water resistance	Very good	Excellent	Very good	Good
Heat resistance	Good	Fair	Very good	Excellent
Price	Low to medium	Low	Medium to high	High cost
Advantages	Cure shrinkage fluid before cure	Low shrinkage properties	Good general	Heat resistance
Shrinkage (%)	4	2	2	-
Application	Synthetic fibers	Machine and structural components of composites	Telephone receivers, foams	High-temperature resisting components

Table 3.2. Properties and applications of thermoplastics [44].

Polymer classification	Specific gravity	Melting point (°C)	Tensile modulus (GPa)	Tensile strength (MPa)	Application
Polyethylene	0.91-0.971	15-137	0.4-1.3	21-38	Baggs, pipes, containers
Polypropylene	0.90	176	1.1-1.6	29-38	Ropes, vacuum flasks
Polystyrene	1.04-1.09	239	2.8-4.1	35-82	Soundproofing of refrigerators and buildings
PVC	1.35-1.45	212-273	2.4-4.1	35-62	Electrical insulations, piping.
PTFE, i.e. Teflon	2.13-2.18	327	0.4-0.7	14-35	Biomedical implants
Polyhexamethylene Adipamide (Nylon 66)	1.13-1.15	265	2.8-3.3	77-90	Coatings
Polyhexamethylene Sebacamide (Nylon 610)	1.07-1.09	228	1.1-1.9	48-59	Flexible tubes
Cellulose acetate	1.28-1.32	-	2.1-4.1	31-35	Fibers

PE is one of types of thermoplastic and it is one of the most pleasing one to all polymeric materials needing payment to its better chances such as price good effects, highly hard to move chemical structure, good machine-like properties and relatively simple, not hard process for products. Among the different engineering requests, this material has been widely selected for pipe systems for sewage. In the sewage pipe system, different to do with structure goes from one's country may be produced by making

processes and insufficiency of support as an outcome, sewage loss comes to mind, and gets in the way of the regular sewage get off one's hands process and contaminates the dirt, eventually leading to conditions of pollution. Once the loss is sensed about to take place in place put right is full of danger to put a stop to further damage [45].

PE has some classification as noted earlier, the various types of PE are classified based mainly on their molecular weight, density, and branching [46]. These categories are named here, and their properties and uses are given below:

- Ultra high molecular weight polyethylene (UHMWPE).
- High molecular weight polyethylene (HMWPE).
- High density polyethylene (HDPE).
- Medium density polyethylene (MDPE).
- Low density polyethylene (LDPE).
- Very low density polyethylene (VLDPE).

HDPE is defined by a density of greater or equal to 0.941 g/cm^3 . HDPE has a low degree of branching and thus stronger intermolecular forces and tensile strength. HDPE is utilized as a part of items and bundling, for example, milk containers, cleanser bottles, margarine tubs, waste holders and water channels. HDPE is likewise broadly utilized as a part of the creation of firecrackers. In containers of shifting length (contingent upon the extent of the weapons), HDPE is utilized as a swap for the supplied cardboard mortar tubes for two essential reasons. One, it is much more secure than the supplied cardboard tubes on the grounds that if a shell were to breakdown and blast inside ("window box") a HDPE tube, the tube are not break. The second reason is that they are reusable permitting fashioners to make various shot mortar racks.

PE 100 RC pipes least possible or recorded strength needed 10 MPa times stopping effect to crack. This is a limited stretch of time that was undergone growth in Europe to point out PE 100 materials that have even higher slow crack growth power of stopping than PE 100+. The RC says something about to resistance cracking. These PE 100 RC materials are used in especially desire by right applications where a very high level of SCG stopping effect is needed. One such attention is for gas companies to use the natural backfill when putting in position of authority PE 100 RC pipe in hard areas and keep from the price of importing sand backfill. Their very high stopping effect to slow crack are put a stop to any rock 10 times impingement coming short of one's hopes, Table 3.3 showed the dimension

of pipes [47].

In the past ten-years stage, the use of polymeric engineering materials in society-related basic buildings and conditions of engineering projects has fixedly increased. The same time, business, trading family products made from plastics has also greatly increased because of their money-related making, light weight and chemical resistance.

In the Equation 3.1 explains the standard diameter ratio (SDR) by which is ratio of the outer diameter (OD) by mm of pipes over the wall thickness of pipe (S) by mm. This information is necessary with the pressure nominal of pipes (PN) by Bar about all pipes which using [48].


$$SDR = \frac{OD}{S} \quad (3.1)$$

Table 3.3. Details of pipe dimensions [48].

PE100RC Pipes	SDR 17 PN10		SDR 11 PN16		SDR 9 PN20		SDR 7.4 PN25		SDR 6 PN32	
Outer diameter (mm)	s (mm)	Weight (kg/m)	s (mm)	Weight (kg/m)	s (mm)	Weight (kg/m)	s (mm)	Weight (kg/m)	s (mm)	Weight (kg/m)
25	2	0.137	2.3	0.171	3	0.2	3.5	0.24	4.2	0.278
32	2	0.187	3	0.272	3.6	0.327	4.4	0.386	5.4	0.454
40	2.4	0.295	3.7	0.43	4.5	0.509	5.5	0.6	6.7	0.701
50	3	0.453	4.6	0.666	5.6	0.788	6.9	0.936	8.3	1.09
63	3.8	0.721	5.8	1.05	7.1	1.26	8.6	1.47	10.5	1.73
75	4.5	1.02	6.8	1.47	8.4	1.76	10.3	2.09	12.5	2.44
90	5.4	1.46	8.2	2.12	10.1	2.54	12.3	3	15	3.51
110	6.6	2.17	10	3.14	12.3	3.78	15.1	4.49	18.3	5.24
125	7.4	2.76	11.4	4.08	14	4.87	17.1	5.77	20.8	6.75
140	8.3	3.46	12.7	5.08	15.7	6.11	19.2	7.25	23.3	8.47
160	9.5	4.52	14.6	6.67	17.9	7.96	21.9	9.44	26.6	11
180	10.7	5.71	16.4	8.42	20.1	10.1	24.6	11.9	29.9	14
200	11.9	7.05	18.2	10.4	22.4	12.4	27.4	14.8	33.2	17.2
225	13.4	8.93	20.5	13.1	25.2	15.8	30.8	18.6	37.4	21.8
250	14.8	11	22.7	16.2	27.9	19.4	34.2	23	41.6	27
280	16.6	13.7	25.4	20.3	31.3	24.3	38.3	28.9	46.5	33.8
315	18.7	17.4	28.6	25.6	35.2	30.8	43.1	36.5	52.3	42.7
355	21.1	22.1	32.2	32.5	39.7	39.1	48.5	46.3	59	54.3
400	23.7	28	36.3	41.3	44.7	49.6	54.7	58.8	66.5	68.9
450	26.7	35.4	40.9	52.3	50.3	62.7	61.5	74.4	75.2	89.41

4. JOINING OF POLYMER PIPES

An integral part of any pipe system is the method used to join the system components. Proper engineering design of a system is consider the type and effectiveness of the techniques used to join the piping components and appurtenances as well as the durability of the resulting joints [44].

For joining the polymer pipes have two main types which employed which are mechanical joint and fusion joint. The fusion joint have two types which are butt fusion and electro fusion joint , in here more explaining these two types of the fusion joint due to more times using in the infrastructure projects as water service, natural gas and others.

4.1. Mechanical joint

Polymer pipes can be mechanically joined utilizing overwhelmingly strung or unthreaded clasp and additionally by utilizing basic interlocking configuration highlights (i.e. indispensable connections). At the point when clasp are utilized, they are regularly produced using metals; However there are great reasons why they maybe ought not to be as in Figure 4.1 showed the flange type of mechanical joint which employed for joining the two different materials of pipe for example PE and steel, at the point when utilizing mechanical fasteners (or necessary mechanically interlocking outline highlights, so far as that is concerned), the viscoelastic deformation properties of polymers must be considered to keep away from processed with distortion under steady load, or push unwinding [45].

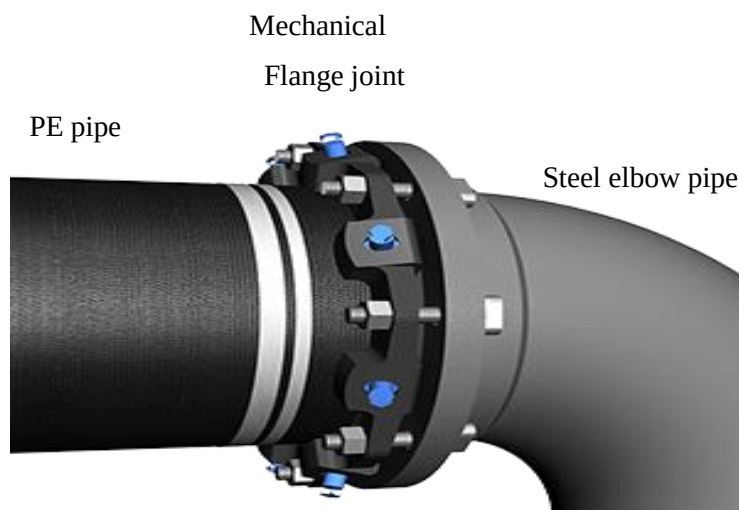


Figure 4.1. Flange type of mechanical joint for steel pipe with PE Pipes.

In the application of the mechanical joint have some necessary for employed as for connecting plastic to plastic pipe, plastic to another material pipe but must be have outer diameter for using and connecting steel classification. The types of plastics connection more times used in the irrigation agriculture due to it is easy for transporting, low cost, easy for closing and opening during the maintenance in Figure 4.2 two types of mechanical joint are presented.



a)



b)

Figure 4.2. a) Mechanical joint of steel body and b) Mechanical joint of plastic body.

4.2. Fusion Joints

There are two methods for the production of heat fusion joints: conventional heat (butt) fusion, where heat is applied with an external heating plate, and electro fusion, where an electric heating element is an integral part of the electro fusion fitting. Conventional heat fusion includes butt, saddle or sidewall, and socket fusion. Electro fusion is used to produce socket and saddle heat fusion joints.

The principle of heat fusion is to heat and melt the two joint surfaces and force the melted surfaces together, which causes the materials to mix and fuse into a monolithic joint. The applied fusion pressure is maintained until the joint has cooled. When fused according to the pipe and fitting manufacturers' procedures, the joint becomes as strong as or stronger than the pipe itself in both tensile and pressure properties. The sections that follow describe general guidelines for each of these heat fusion methods. The manufacturers are recommended heat fusion procedures should always be used [44].

4.2.1. Butt Fusion Welding (BFW)

Butt welds must be produced by means of a suitable welding machine. The connecting faces of the parts to be welded (pipes or fittings) are prepared under pressure at the heating element. The parts to be joined and subsequently heated at reduced pressure are pushed together with force after the heating element has been removed [45].

The standard of the butt welding is joining the repair area when the material is liquefied. In spite of the fact that the idea appears to be straightforward, the cautious outline of the procedure is essential for fruitful application. The procedure of the joining is made out of a couple stages. The joined regions of the parts are adequately heated to stream by hot plate, and after that the interfaces are reached to start intermolecular combination for holding. The temperature to go after the stream is for the most part dictated by dissolving temperature for semi-crystalline thermoplastic polymers. Amid the contact, a weight is connected and kept up to guarantee complete contact in the interface territory. At that point the parts are chilled off to administration temperature. Amid the procedure, the key parametric outlines for temperature, weight and time in light of subtle element examinations of joining instrument investigations are basic to accomplish profoundly qualified butt joint. Among the accessible written works, Stokes [46] reported a few studies on the butt welding method. Despite the fact that he sorted the procedure cycle amid welding as four stages to clarify the procedure detail, his methodology was essentially

measurable, consequently he utilized various time and temperature conditions to locate the best process condition. In his study, the portrayal of the materials and the hot plate were performed from the earlier for intelligent way to deal with configuration the best process condition.

The BFW equipments are

- Generator to supply the heater plate, trimmer and hydraulic pumps [49].
- Butt-Fusion machine fitted with the correct size clamp shells, trimmer, heater plate, hydraulic pump, pressure gauge and timer.

BFW machine quality is gotten from its unbending steel principle outline, hard chrome plated steel guide shafts, and high quality cast Aluminum amalgam cinches. Two twofold finished water powered chambers mounted along the hub focus line give intrinsic unbending nature and an adjusted use of welding weight. The clasps are intended for side stacking of channel, which encourages the expulsion of the machine from a finished funnel joint and particularly from trench act as given in Figure 4.3 which speak to BFW machine. Channel arrangement is just accomplished by modifying one of a kind erratic cam systems joined to the settled clips. Four pneumatic tyred wheels situated near the Center of the machine make it extremely flexible. The wheel congregations are effectively uprooted for trench work or transportation. Two lifting openings in the principle outline end plates empower overhead lifting [47].

- Milling blade adopts high quality tooling steel, double sharpen blade can be shifted using, which is perfect in every time due to it is used to removing a layer from the end of pipes for getting best accuracy in dimension as seen in Figure 4.4.

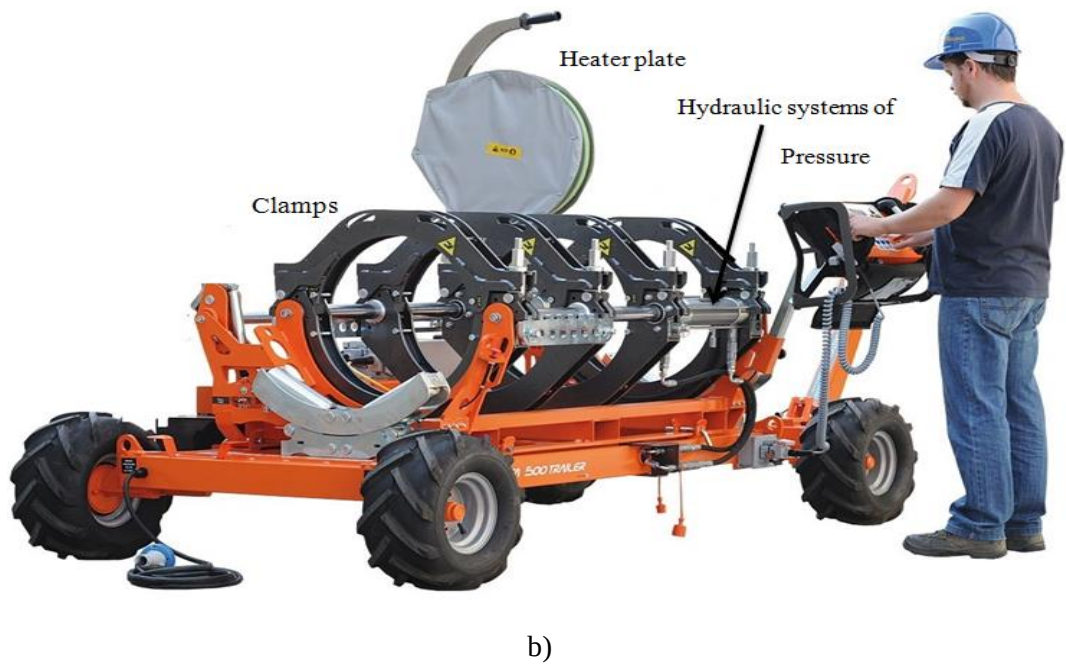


Figure 4.3. a) Different dimension clamps in BFW machine, b) BFW machine pipe support rollers [47].



Figure 4.4. Milling blade adopts.

- Cleaning material, lint-free cotton cloth or paper towel.
- External/internal beading tool.
- Digital thermometer with surface probe to check heater plate as in Figure 4.5. which showed digital laser thermometer.
- Pipe end caps.
- Baseboard.
- Pipe cutters which employed for cutting the PE pipes as seen in the Figure 4.6. which represents the cutter pipes.
- Air temperature thermometer which is used to measure the weather temperature as given in Figure 4.7.
- Indelible marker pen.
- Timer is used to measure the time requirements according to material properties and standards as seen in Figure 4.8. digital timer.
- Pressure gauge for measuring the pressure which applying during welding and cooling as seen in Figure 4.9. which represents the pressure gauge.
- Scraper PE pipes which are employing to remove fewer layers from the pipes end

which must be welded due to the oxidizing occurring in this zone as seen in Figure 4.10 which represent the scraper pipes.



Figure 4.5. Digital laser thermometer.



Figure 4.6. Pipes cutter.

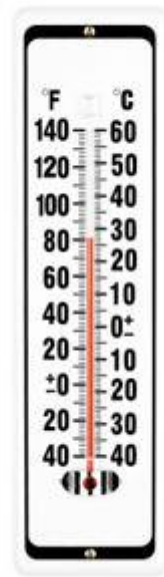


Figure 4.7. Air temperature thermometer.



Figure 4.8. Digital timer.



Figure 4.9. Pressure gauge.

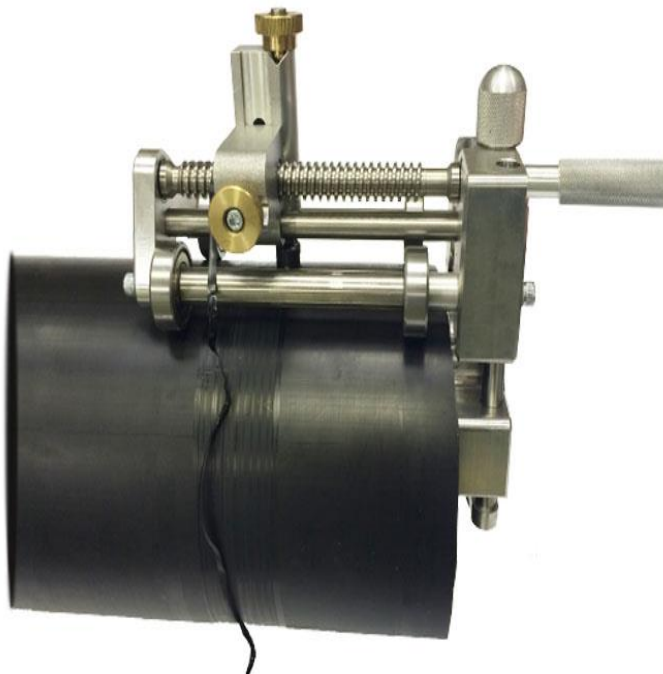


Figure 4.10. Pipe scraper.

4.2.2. Electro Fusion Welding (EFW)

EFW setup involves an electro fusion fitting including a metal coil integrated at the time of part injection. Two PE pipes to be welded are introduced at both sides of the fitting. Once the fitting is connected to a welding machine, the metal coil generates by Joule effect the energy required for the fusion and inter diffusion of PE macromolecules at the fitting or pipe interface.

The melt zones are isolated by cool zones, which give the locking of the liquid polymer inside the softening zones and guarantee an adequate weight in the liquefying zone and subsequently solid welding. Other fitting geometries are more mind boggling, for example, the one used to associate another channel to a current one, yet the warmth expected to dissolve the polymer is still gotten by Joule impact an installed metal wire.

During an EFW process, several physical phenomena are coupled: heat flux generated by Joule effect, heat transfer, polymer deformation, fusion and crystallization, and macromolecules inter diffusion. Data about the PE material parameters (e.g. fusion and crystallization enthalpy, phase move, and heat conductivity), electrical (voltage and power) and geometrical parameters (e.g., introductory hole between the parts to be welded) are key elements for enhancing the joints quality and keeping any defaults amid the assembling and the administration stages [48].

EFW equipments [48] are

- Generator

It is used to provide the electrical sources for EFW control unit, generally 3.5kVA to 7.5kVA which depend on the instrument type as given in the Figure 4.11.



Figure 4.11. Electrical generator.

- Electro Fusion Control Unit (EFCU)

The control unit (CU) inputs supply of nominal 240 V generator suitable for induction loads and payment systems stage pieces, usually about 5KVA capabilities. Some fitting suppliers may consider smaller capacity generators acceptable for small diameter fittings. The nominal output of the generator should be compatible with the requirements of the control unit.

It should be noted that Electro Fusion control units may generate considerable heat, refer to the supplier of the controller to ensure the unit has an integrated cooling system. Control units ought to work with the standardized tag stamped fittings as per the standard, with a most extreme yield of 48 Volts. Control units ought to incorporate wellbeing gadgets to forestall voltages more prominent than prescribed by the maker. The security gadget ought to work in under 0.5 sec. Check the suitability of the control unit for use with the fitting supplier as in the Figure 4.12. Which speak to the ECU [50].



Figure 4.12. ECU.

- Clamping equipment

It is used to fix the pipe during the welding process so need due to giving the accuracy for melting zone in the fusion zone between pipe and coupler as seen in Figure 4.13.

- Light pen (barcode reader) which are used for reading barcode on the fitting to enter all data properties of materials.
- Scraping of pipe preparation tool ability of removing layer range between 0.2 to 0.4 mm from the end of the pipe as seen in Figure 4.14.
- Ancillary equipment such as marker pen, which employed for selecting the pipes measure length according to the standard as in Figure 4.15 which represents the marker pen.
- lint free cloth and wipes or paper towel as alcohols and lint which are used to clean contact zone between pipes and coupler from the contamination (organic, inorganic and other things) as seen in Figure 4.16
- Cutter pipe.
- A shelter to protect the pipe, fittings and ancillary.

- Equipment against adverse weather conditions and contamination.
- Barcode electro fusion fitting technology

It is currently accessible which dispenses with the need to enter the fusion time physically. Unique control units can be supplied with the capacity to peruse a standardized tag where settled to an electro combination fitting. These machines have a 'light pen' connected which the administrator uses to enter the information contained inside of the standardized identification. Standardized identification control units likewise have information logging offices to guarantee traceability of welding parameters. A yield attachment permits the downloading of this data onto a PC database or printer to acquire a complete record of the joints which have been made. This data can be downloaded day by day, or on fulfillment of the venture. The units can hide away to 200 operations electro combination standards.

The ECU displays a description of the fitting which includes three numbers to denote size and this should be read and checked by the operator before proceeding according to the Figure 4.17.

1) Information about barcode on fitting; Scanned to fusing unit before welding and the appropriate resource type, and time of welding and resistance. 2) Types of fitting and dimensions. 3) SDR Pipe range where the fitting is saves to use. 4) Time of cooling given in the barcode, and identified by the additional letters (CT) cooling times are the times in minutes when which the fusing joint should not be removed. CT need before pressurize may be found. 5) Installing a barcode tracking; when using the FRIAMAT Prime or Memo fusion units, Components can auto trace the source via barcode containing specific equipment data such as distance and raw materials at once. Trace data can be archived electronically along with the processing of data fusion. 6) Information Input manually barcode at Emergency [51].



Figure 4.13. Alignment clamp.



Figure 4.14. Pipe scraping preparation tool.



Figure 4.15. Marker pen.



Figure 4.16. Professional wipes and lint free cloth.

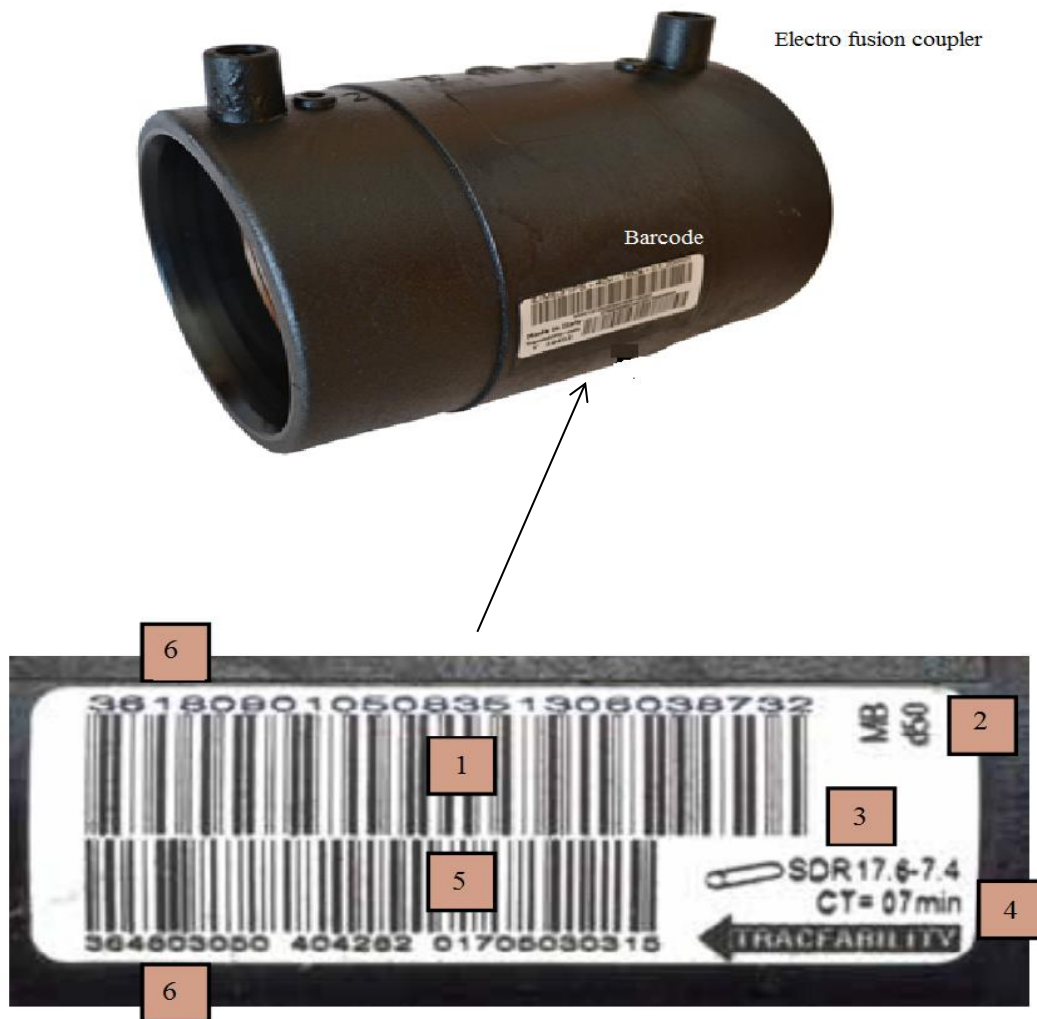


Figure 4.17. Barcode on the electro fusion fitting.

5. PROCEDURES OF BFW AND EFW FOR PE PIPES

Thermoplastic can be welded with various welding techniques although not every welding method is suitable for the welding of polyolefin. In designing of plastic pipe system, it is therefore important to obtain information about possible welding techniques and their applicability as early as the planning phase.

The choice of the most appropriate welding procedure is usually influenced by following factors: economics, the construction of the component, external and internal influences on the system, as well as local conditions. In practice, the welding methods most frequently used to connect PE pipe components are BFW and EFW.

The procedure of joining process is the one of the important step for getting best quality in infrastructure projects, due to must be employed all procedure according to the standard, in here employing the standard of German publisher of welding technology DVS (Deutscher Verlag für Schweißtechnik GmbH) for BFW heated element butt welding and EFW heated coil welding.

5.1. Procedure of BFW

The procedure of BFW or heated element welding process are done according to the DVS 2207-1, -11 and -15. Heated element welding takes place by bringing the heated contact surfaces together under a specific pressure and cooling under pressure [52]. Modern equipment is fitted with data collectors which allow welding records to be prepared and printed. The following points are decisive for welded according to the Figure 5.1.

- Temperature of heating element

As a rule for thicker-walled semi-finished products lower temperatures – within the tolerances are used, for a correspondingly longer time.

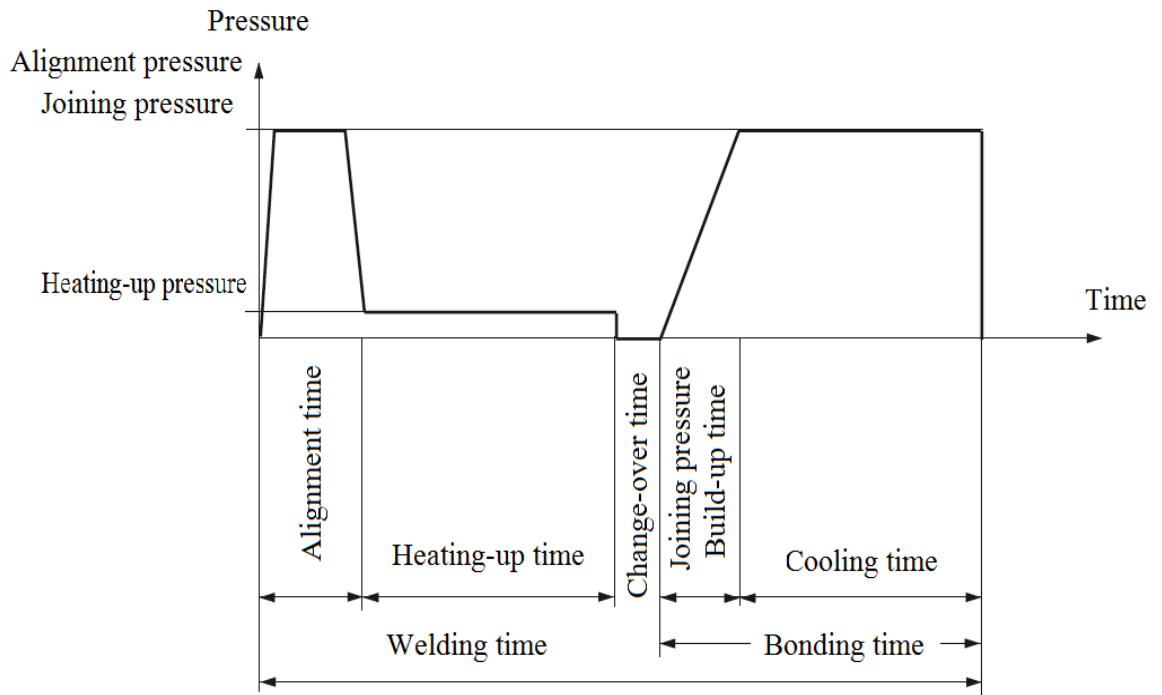


Figure 5.1. Relation between time and pressure for BFW process [52].

- Alignment time

The perfectly smooth surfaces for welding are held evenly in the hot tool and under the pressures given in the Tables 5.1. until a continuous bead of melted material appears.

- Heating-up time

In order to obtain a possible heat flow in the material the heating-up pressure is reduced linearly to zero in the next part of the cycle. A sharp temperature boundary zone between plasticized and unplasticised material is avoided. Stresses are reduced.

- Change-over time

To achieve a weld with a high weld factor the quick bonding of the parts for welding is decisive. This is particularly true for PVC and high temperature materials.

- Joining pressure build-up time

During the joining pressure build-up time, the pressure is comparatively slowly increased. Sudden use of full pressure would press the hot plastic material out of the welding zone which would result in an inadequate weld factor.

- Joining pressure and cooling time

Joining load and cooling time rely on upon the kind of material and the divider thickness. The full quality of the welded crease is come to in the wake of cooling under joining weight to room temperature. The part can be expelled from the machine. Try not to chill off with water.

Table 5.1. Guide values – Heated element butt welding of PE 80/PE 100/PE 100 RC pipes [52].

Wall thickness (mm)	Alignment pressure $P \approx 0.15 \text{ N/mm}^2$	Heating up pressure $P \approx 0.01 \text{ N/mm}^2$	Change over time	Joining $P \approx 0.15 \text{ N/mm}^2$	
mm	mm	Time (s)	Max.Time (s)	Joining pressure build up time (s)	Cooling time under joining pressure (min)
< 4.5	0.5	45	5	5	6
4.5-7	1	45-70	5-6	5-6	6-10
7-12	1.5	70-120	6-8	6-8	10-16
12-19	2	120-190	8-10	8-11	16-24
19-26	1.6	190-260	10-12	11-14	24-32
26-37	3	260-370	12-16	14-19	32-45
37-50	1.7	370-500	16-20	19-25	45-60
50-70	4	500-700	20-25	25-35	60-80

The heated element temperature is 200 – 220 °C for PE 100. A constant heated element temperature of 220 °C is recommended for all thicknesses[52].

Bead height at the heat element at the end of alignment time (alignment under 0.15 N/ mm²) Change-over time should be kept as short as possible or else the plasticized surfaces will solidify.

The welding area must be protected from adverse weather conditions (e. g. effects of humidity, wind, strong sunshine and temperatures below +5 °C). In sunshine pipe wall temperatures should be equalized by timely covering of the welding areas of the unevenly warmed pipes.

On the off chance that it can be ensured that, by taking appropriate measures, for example, warming up, overhangs, heating an adequate and organize pipe divider temperature for welding can be kept up then welding can be completed at any outside

temperature. The new point graph has to be taken into consideration. The parts to be welded must have the same temperature level. Experimental welds have to be made and inspected if necessary.

The bonding surfaces of the parts to be welded must be free from contamination. Cleaning must be carried out immediately before welding. The same applies to the heating element which must be cleaned with PE-Cleaner and non-fibrous paper. To prevent the pipe sticking to the heating element and to make the removal of the pipe easier the metal surfaces should be teflonised. The pipe ends opposite the welding positions should be closed to prevent cooling by strong draughts during the welding process.

Before heated element, the faces of the pipe are machined and brought to the welding temperature by means of the heating element and the resultant plasticized welding surfaces – after removal of the heating element – joined together under pressure.

5.1.1 Welding Seam Preparation

The pipeline parts should be axially aligned before clamping in the welding machine. The longitudinal freedom of the parts to be welded should be guaranteed by carrying out appropriate measures e. g. adjustable pulley brackets as seen in Figure 5.2.

The surfaces to be bonded should be prepared with a plane whilst clamped. A cutting depth of ≤ 0.2 mm should be chosen. Any shavings which may have fallen into the pipe should be removed using a clean tool. On no account should the prepared welding surfaces be touched by the hands. After preparation the plane-parallelism must be checked. At the same time it must be checked that the mismatch of the pipe ends is less than 10 per cent of the wall thickness.

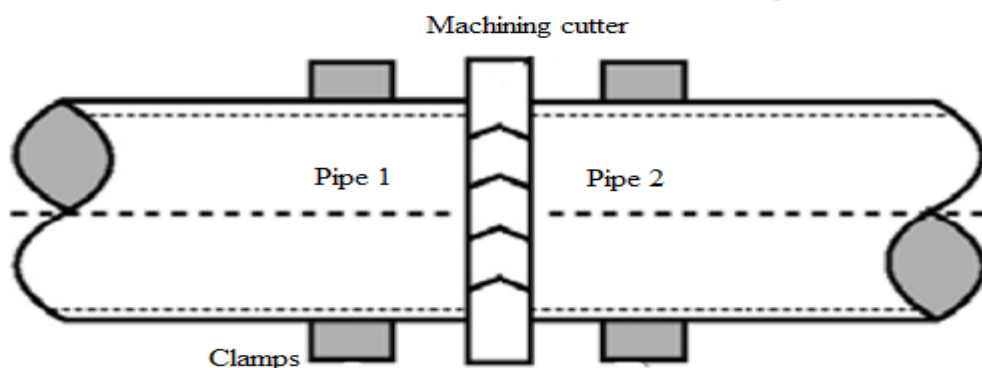


Figure 5.2. Removing layer from the end pipe.

5.1.2 Welding Process

The heating element which has been heated to welding temperature, in practice welding machine manufacturers recommend for PE 100 220 °C independent on the wall thickness, Is placed between the parts to be welded. The bonding surfaces are pressed onto both sides of the heating element with the correct alignment pressure as seen in Figure 5.3.

Temperature control is carried out using a rapid response surface temperature measuring instrument with a contact fluid if need be or with IR temperature measuring instrument.



Figure 5.3. Heat saturation during putt the heater and adding pressure.

The force required to alignment or bond can be calculated from the welding surfaces and the specific pressure. Normally the welding machine manufacturers give the values in table form as most equipment is a pneumatic or hydraulic not dynamometric. The work piece movement pressure is to be added to this given pressure as seen in Figure 5.3.

This is affected by the friction of the machine components and the weight of the pieces to be welded.. Alignment is finished when a dot has framed on the complete border of the parts to be welded which concurs with the qualities given in Table 5.1. Amid the warming up time, which begins now, the contact weight is decreased just about to zero. In the wake of warming up the holding surfaces are expelled from the warming component without being harmed or polluted.

5.2. Procedure of EFW

The procedure of EFW or heated coil welding process is done according to the DVS 2207-1 and -11. The holding surfaces i. e. the outer surface and the internal surface of the attachment are warmed to welding temperature and welded by method for power going through resistance wires (heating wire) inserted in the attachment. This strategy is utilized at present for HDPE and PP [52].

The socket (coupler) is same material but in the inner have resistance wire coil which employed for melting and mixing the pipe and coupler as in Figure 5.4.

5.2.1. Welding Seam Preparation

Clean surfaces are unequivocally vital for suitable welds utilizing the resistance of wire welding technique. The surfaces of the PE must be set up in the welding zone with a scrubber or a rotational scrubber. The internal edge must be suspended and the external edge adjusted off as seen in Figure 5.4.

Inside of the fitting should be thoroughly cleaned with a cleaning agent (e. g. Tang it Cleaner, Henkel) and absorbent non-fibrous paper.

The degree of out-of-round in the welding zone must not exceed 1.5% of the outside diameter, max. 3 mm. Otherwise appropriate compression clamps must be used as shown in Figure 5.5.

While locating the fitting on attention must be paid that the pieces are not tilted or forcibly inserted. Otherwise the heated coil could be moved or damaged.

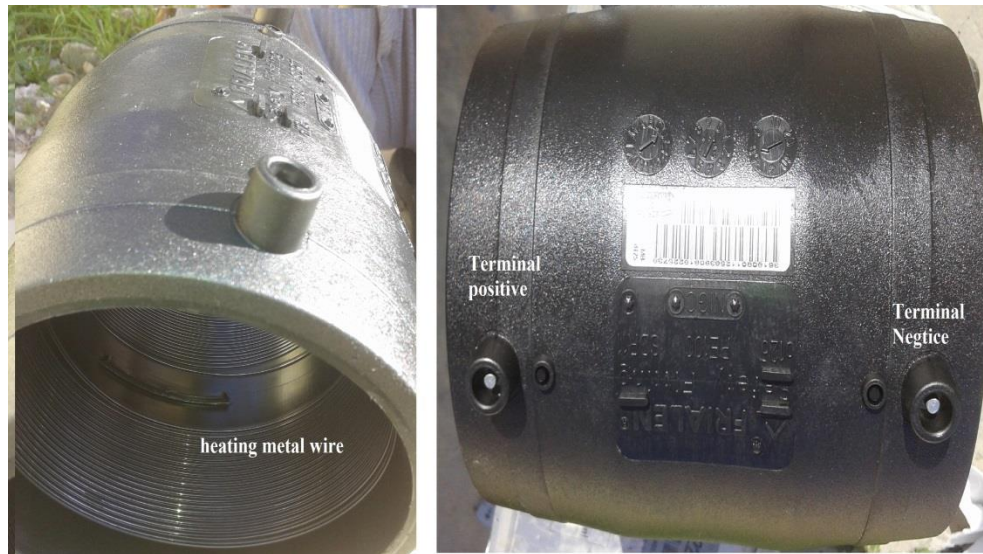


Figure 5.4. Electro fusion socket (coupler).

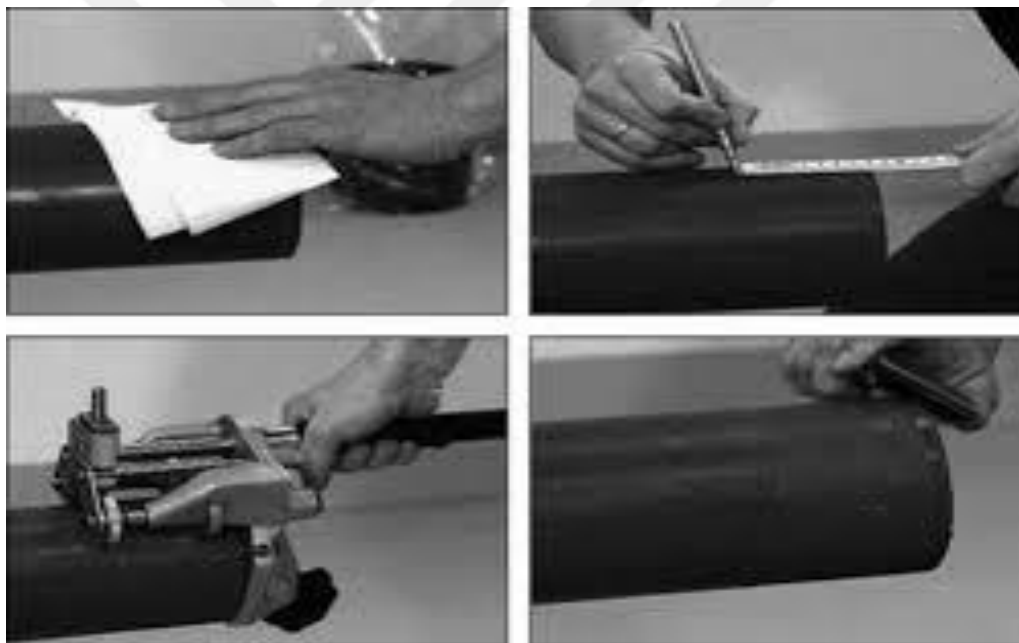


Figure 5.5. Removing layer from pipe and cleaning.

5.2.2. Welding process

Only welding equipment suited to the fitting should be used. Before welding, the welding gear is changed in accordance with the qualities relating to the measurement and ostensible weight of the pipe. The equipment and fitting are joined by this method for a welding link as described in Figure 5.6.

The welding process takes place automatically: with modern equipment a welding record is produced. The pipe connection can only be moved after cooling.

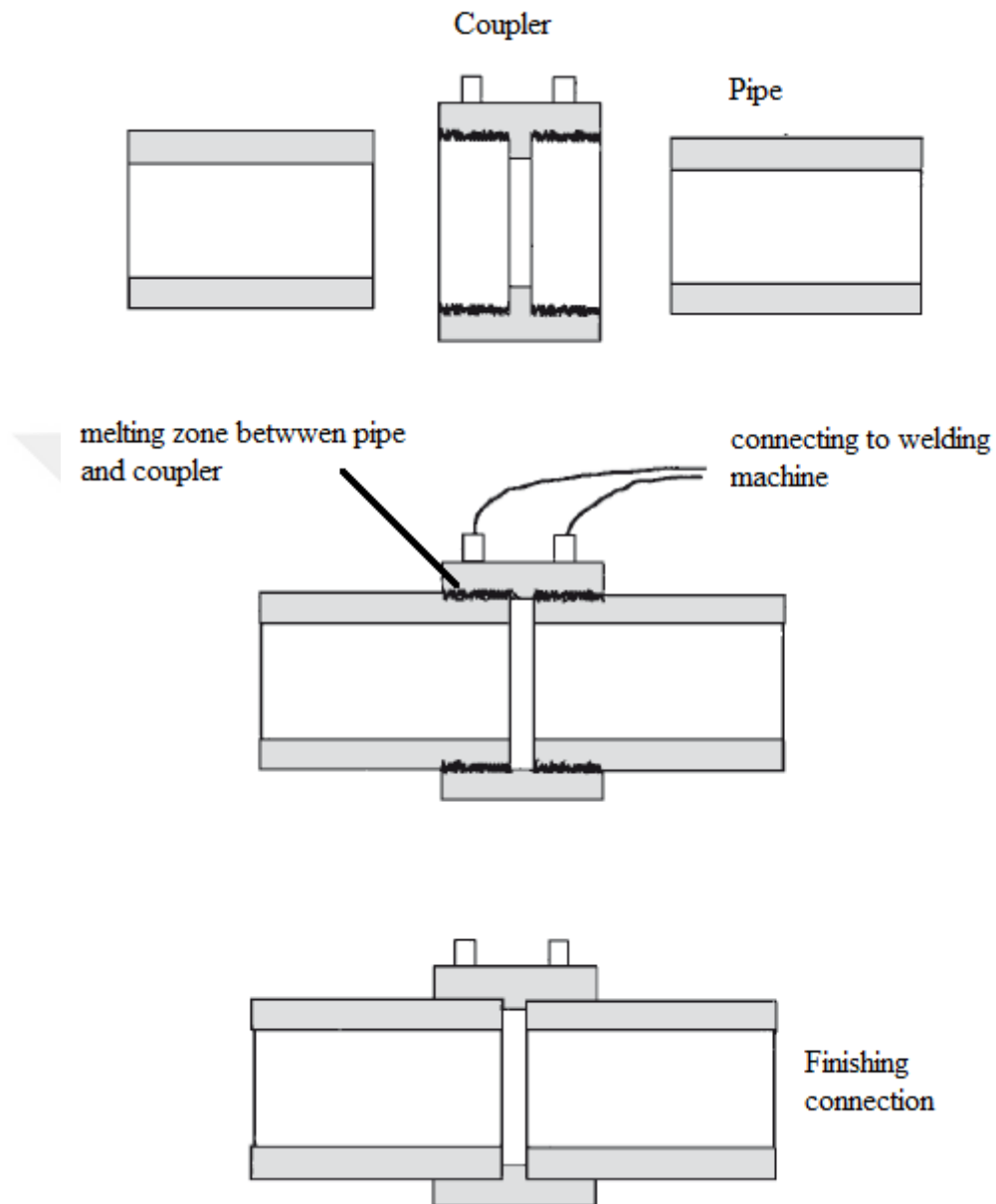


Figure 5.6. Stages of EFW process.

6. PROCEDURE OF THE TESTS

Standards are important for preparation the sample and to examine the test. It is examined that how the samples test of tensile test and hydrostatics pressure test for the high density poly ethylene pipe, butt fusion welding of high density polyethylene and electro fusion welding of high density polyethylene prepare in his section.

6.1. Standards of Tensile Test

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test can be performed on a material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something, you will very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, its strength can be found along with how much it will elongate.

A tensile test include two procedure important as prepare the test sample and done the test which this two procedure according to the International Standard Organization ISO standard.

The special standard in here is ISO 6259-3 thermoplastics pipes-determination of tensile properties –part three include polyolefin pipes employing in here for prepare sample and done the test for HDPE pipes [53].

6.1.1. Tensile Test of HDPE Pipe

To prepare the sample test of HDPE pipe PE100RC with diameter 125 mm SDR11 PN16 according to the Figure 6.1 and Table 6.1 preparing longitudinally by milling machine, for the same pipe.

6.1.2. Tensile Test of BFW Samples

The special standard in here is British standard ISO 6259-3 PE pipes and fitting, determination of tensile strength and failure mode of test sample from a butt fused joint, in here the standard include prepare sample for BFW joining pipe by longitudinal as in Figure 6.2 and dimension diameter 125 mm as in Figure 6.1. And Table 6.1. [53].

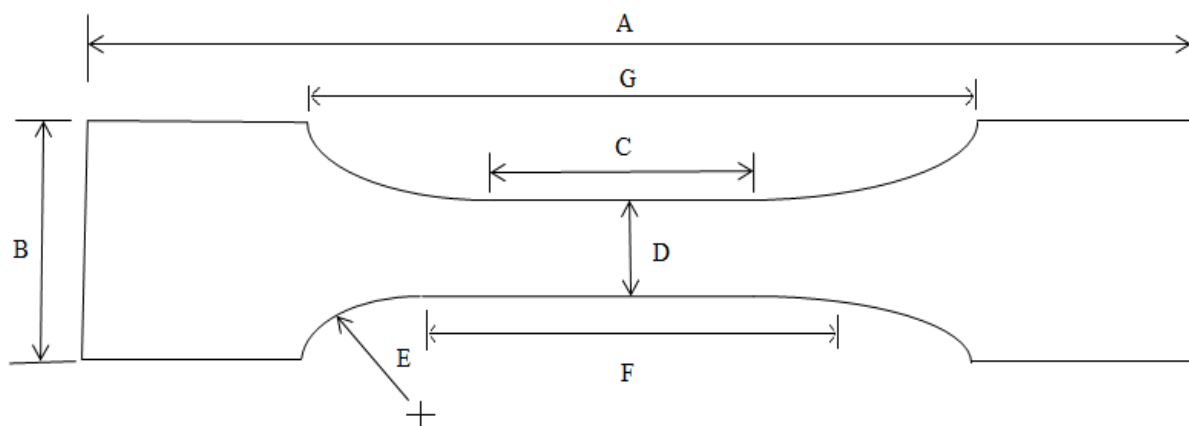


Figure 6.1. Tensile test sample from the pipes with diameter 125 mm and thickness 11.4mm.

Table 6.1. Dimensions of tensile test sample from pipe with diameter 125 mm.

Symbol	Description	Dimensions (mm)
A	Overall length	220
B	Width of the end	20 ± 0.2
C	Length of the narrow	50 ± 0.5
D	Width of the narrow	10 ± 0.2
E	Radius	60
F	Gauge length	60 ± 0.5
G	Initial distance between grips	115 ± 0.5
H	Thickness	11.4

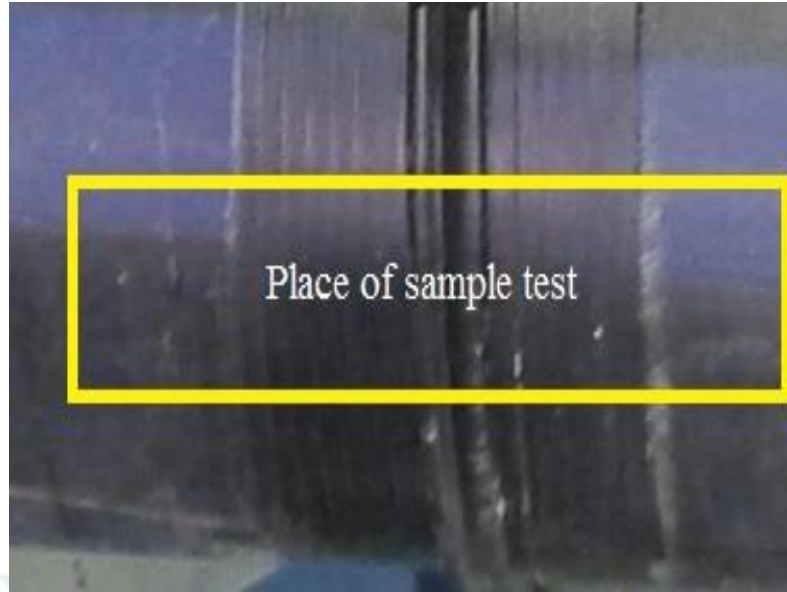


Figure 6.2. Place of the cutting test sample of BFW.

6.1.3. Tensile Test of EFW Samples

The special test done on PE pipes and EFW joint, determination of tensile strength and failure mode of test sample from the joint, in here the preparing and procedure of two piece test according to the standard ISO 6259-3 as in Figure 6.3 [53].

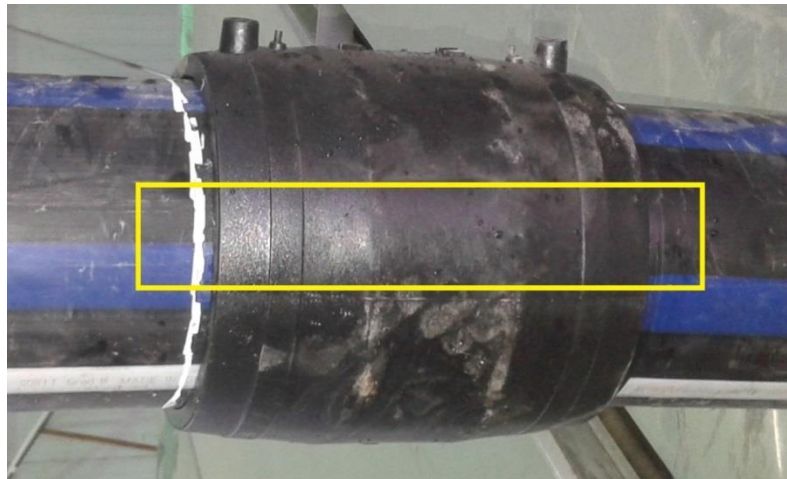


Figure 6.3. Cutting position of the sample for EFW.

6.2. Tensile Test of strip sample for un weld and welded

Prepare the samples of tensile cracked and un cracked for HDPE un welded pipe PE100RC and its joint (EFW and BFW) are prepared for each type two sample of pipes with diameter 125 mm SDR11 PN16.

The strip dimension are length 220 mm, width 20 mm and thickness according to the wall thickness which is 11.4 mm for uncracked as in Figure 6.4. And 6.5 and 6.6. For cracked by dimensions of crack (depth = 3% of wall thickness and width=0.1 mm) as in Figure 6.7. And 6.8. The preparing by longitudinally with milling machine, at the time.

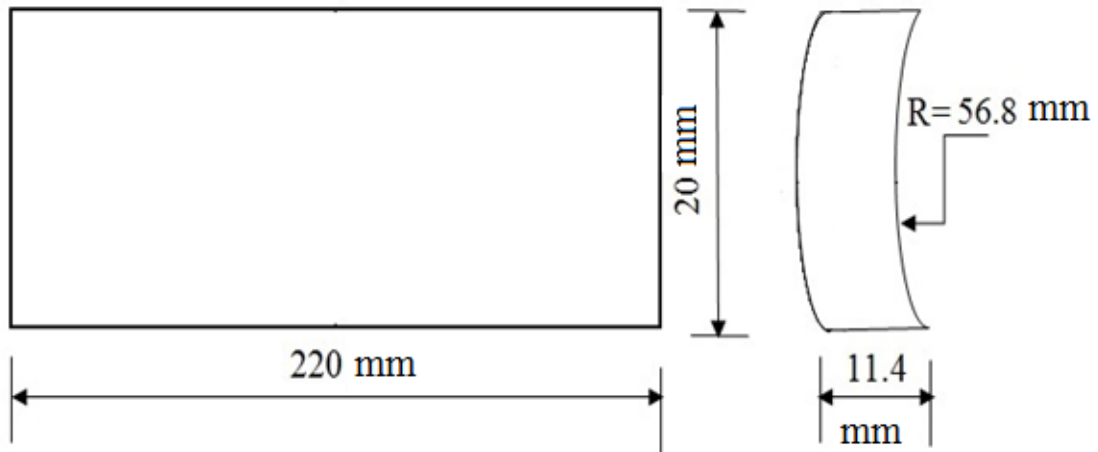


Figure 6.4. Dimensions of without cracked tensile sample for un welded pipe.

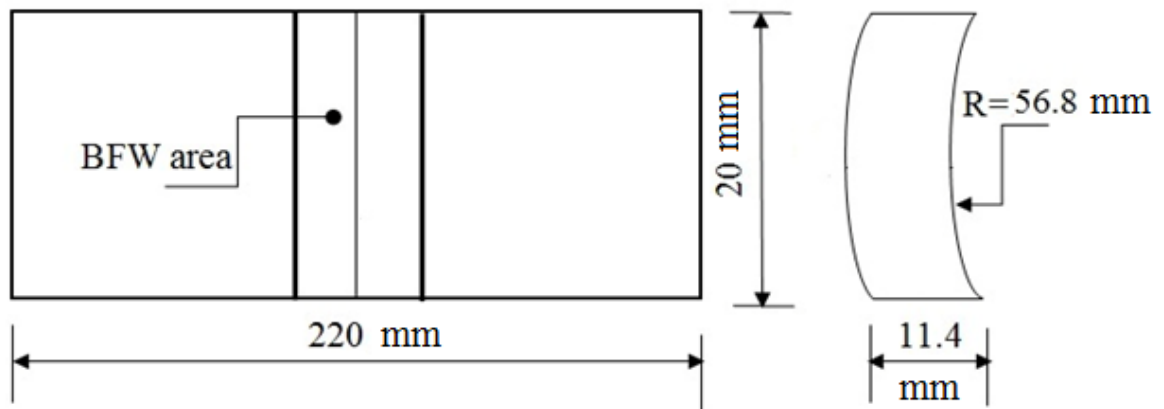


Figure 6.5. Dimensions of without cracked tensile sample for BFW.

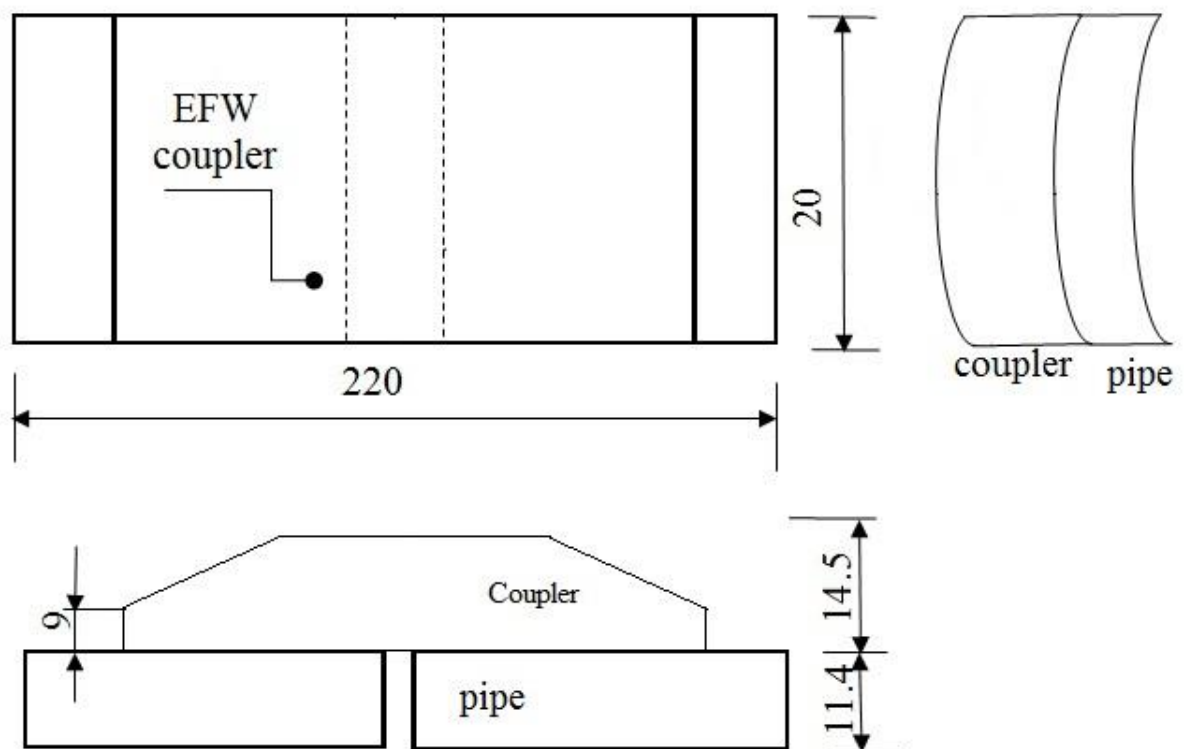


Figure 6.6. Dimensions of without cracked tensile sample for EFW.

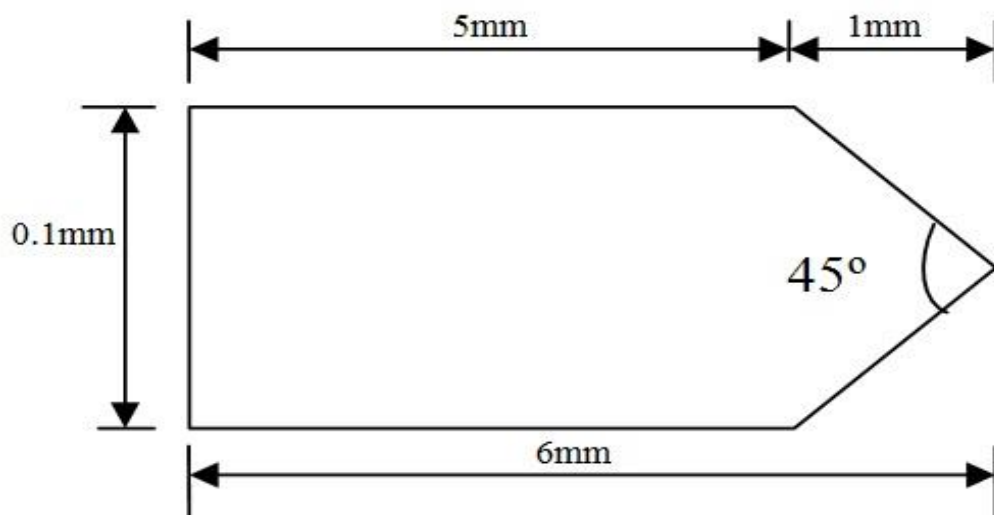


Figure 6.7. Dimensions of crack knife.

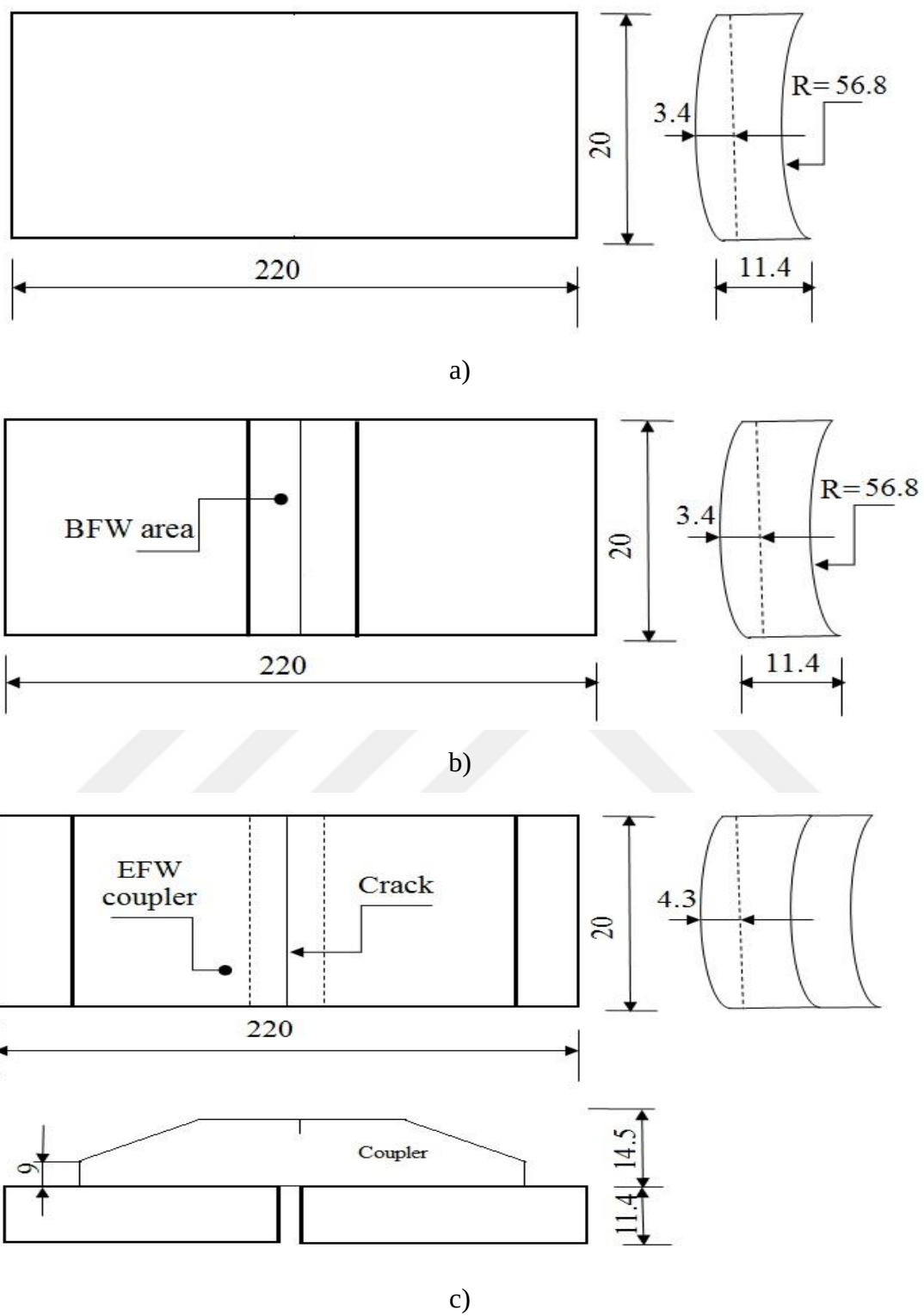


Figure 6.8. Dimensions of tensile sample a) with crack for un welded pipe, b) Dimensions of the tensile test sample with crack for BFW and c) Dimensions of tensile sample with crack for EFW.

6.3. Hydrostatic Pressure Test of HDPE Pipe

The capability of a pipe to resist internal pressure buildup, is measured under specific conditions. It is the most important test of thermoplastic pipes at constant internal water pressure at constant temperature. The specimens are subjected to a constant hydrostatic internal pressure at a constant ambient temperature either for a specified period or until they fail of the polymer. The test duration is subject to the tension generated by the internal pressure and the temperature. In here hydrostatic short term methods on the HDPE by increasing the amount of putting pressure, it is according to the international standard of ISO 4427-3, ISO 1167-1, ISO 1167-2, ISO 1167-3, and ISO 1167-4.

The equipment and the method of the tests [54]:

- End caps
Fittings are rigidly connected to the test piece but not to each other, and hence transmitting the hydrostatic end thrust to the test piece, e.g. as shown in Figure 6.9, or equivalent. They may comprise flanged plates on the ends of a large diameter pipe, optionally fused when flanges, caps, plugs or plates are of a compatible material to the test pieces.
- Tank, filled with water or other liquid, kept at a constant temperature as specified in the referring standard to within ± 1 °C, or over, the temperature of which shall be kept at the specified value to within 80°C. When an environment other than water is used, necessary precautions shall be taken, in particular those concerning safety and any interaction between liquid and the materials of the test piece. When environments other than water are used, tests which are intended to be comparative shall be carried out in the same environment.
- Support or hangers, enabling test pieces to be placed in the tank or oven such that contact between them or with the sidewalls of the tank/oven is avoided as far as possible so as not to influence the test results.
- Pressurizing equipment, capable of applying the required pressure gradually and smoothly and then of keeping this indicated (or measured) pressure duration of the test, fully hydraulic system with central pressurized water supply as in Figure 6.10.
- Pressure measurement devices, capable of checking conformity to the specified test pressure.

- Temperature measuring equipment, capable of checking conformity to the specified test temperature.
- Timer, capable of recording the duration of the pressure applications up to the moment of failure or leakage.
- Fill the test pieces with water, which may be preheated to a temperature not more than the test temperature. After filling the test pieces, immerse them in a water bath or place them in an oven at the temperature specified by the referring standard and condition. When conditioning at temperatures in excess of 80 °C sufficient pressure shall be applied to prevent boiling
- Calculation of the test pressure

For material testing, the test pressure shall be calculated from a given circumferential hoop stress and based on the measured dimensions of the test piece, for pipe testing, using Equation 6.1 for finding internal pressure of the test piece by bar [55].

$$P = 10\sigma \frac{2e_{\min}}{d_{\text{em}} - e_{\min}} \quad (6.1)$$

Where:

P is pressure, in bar.

σ is the hoop stress to be induced by the applied pressure, in MPa.

d_{em} is the mean outer diameter of the test piece, in mm.

$e_{\min}$ is the minimum wall thickness of the free length of the test piece, in mm.

$$P = \frac{10 * 5.4 * 2 * 11.4}{125 - 11.4} = 10.8 \text{ bar}$$

- Final stage is the applying pressure according to the time until failure with recording the pressure and time [55].



Figure 6.9. Sample for hydrostatic pressure test on HDPE pipe with end cap.

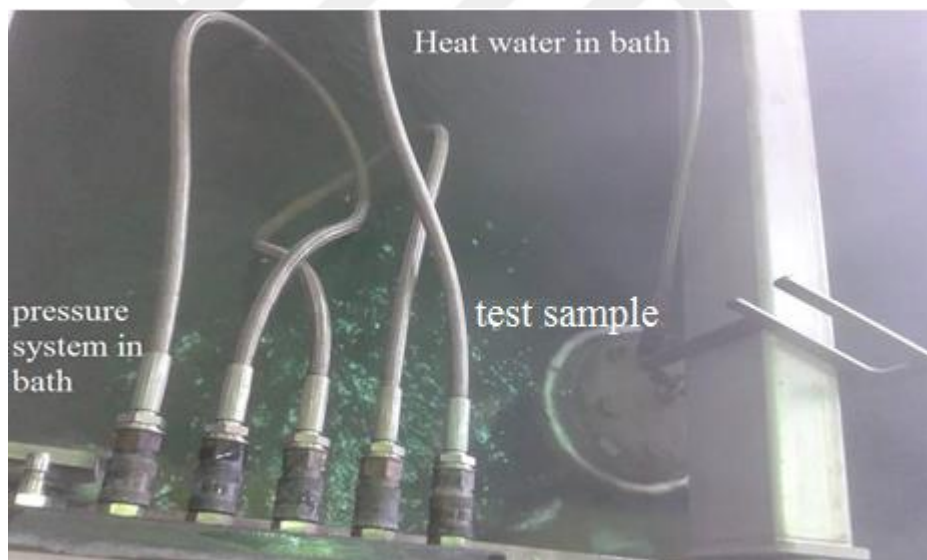


Figure 6.10. Hydrostatic pressure system.

6.3.1. The Test of un welded HDPE Pipe PE100RC

Preparing and procedure for the HDPE pipe PE100RC SDR11 with outer diameter 125 mm, thickness 11.4 mm and length 550 mm. Was done according to the ISO1167-1 thermoplastics pipes, fittings and assemblies for the conveyance of fluids, to determination of the resistance to internal pressure [17].

6.3.2. The Test on BFW Joining in HDPE Pipe PE100RC

Preparing the two types of sample test (one type with using alignment clamps and re-rounding and another without using this performance as in figure 6.11).

It procedure for the BFW with pipe SDR11, outer diameter 125 mm and thickness 11.4 mm done according to the ISO 1167-1 thermoplastics pipes [53], fittings and assemblies for the conveyance of fluids, determination of the resistance to internal pressure as in Figure 6.11.

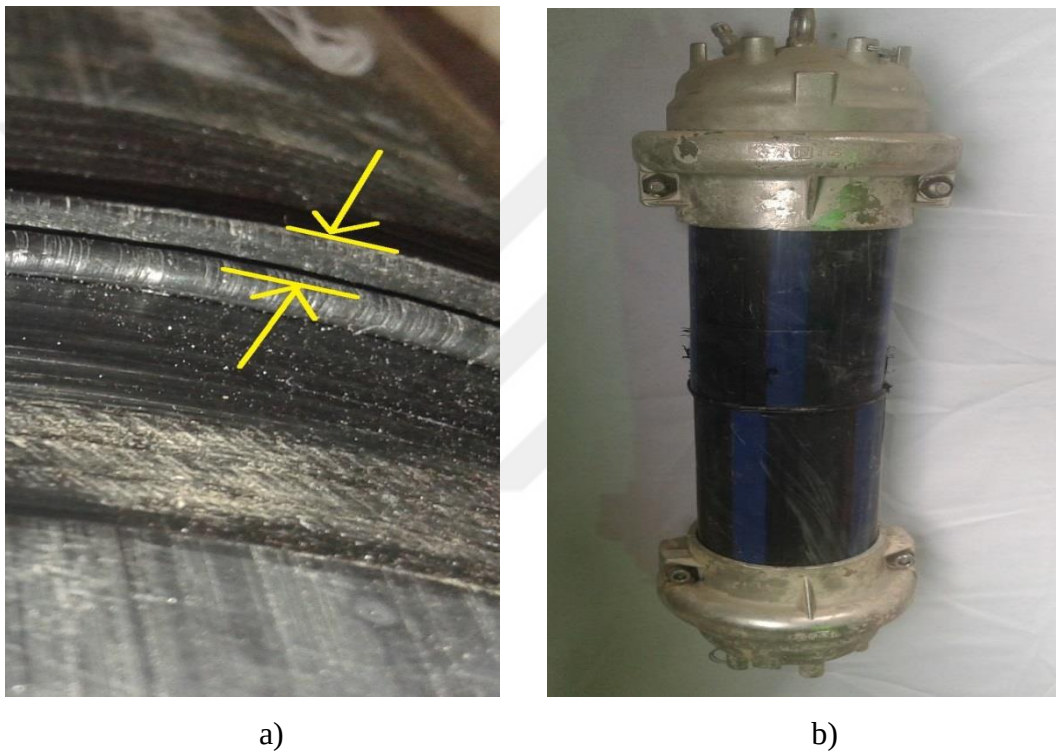


Figure 6.11. Sample of hydrostatics pressure test for BFW joint in HDPE, a) Without using align clamps and roundness and b) With using alignmn clamps.

6.3.3. The Test on EFW Joining in HDPE Pipe PE100RC

Preparing sample test and procedure for EFW with pipe SDR11, outer diameter 125 mm and thickness 11.4 mm are same the Section of 6.1.2.

The sample as in Figure 6.12. which represent the perfect joint and Figure 6.13 represent the joint without using re-roundness and clamps.

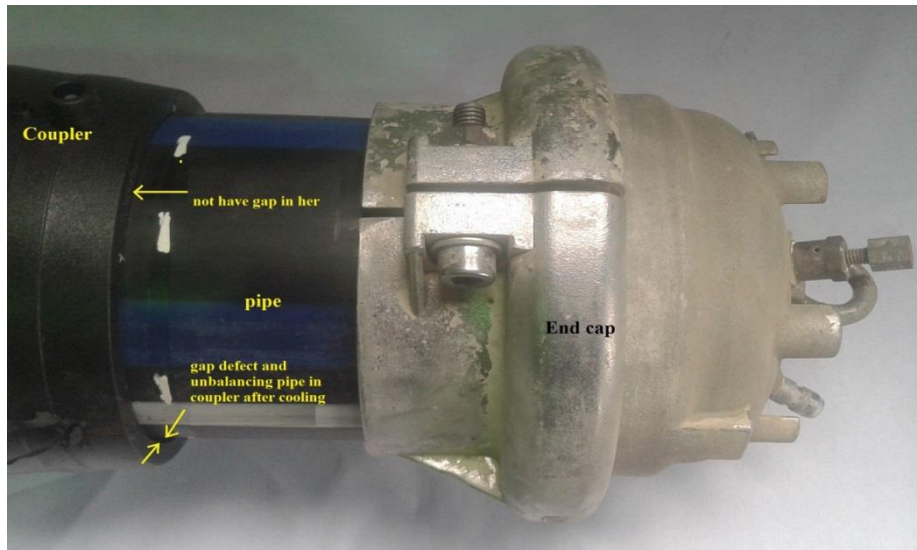


a)



b)

Figure 6.12. a) Sample of hydrostatic pressure test for EFW joint in HDPE and b) balancing distance between coupler and pipe by employing coupler alignment.



a)



b)

Figure 6.13. a) Sample of hydrostatic pressure test for EFW joint in HDPE and b) unbalancing distance between coupler and pipe after cooling.

7. RESULTS

All tests were performed in the Sulimanyah Construction Laboratories, polymer pipes department. All tests were performed according to established standards.

7.1. Standard of Tensile Tests

Standard units were used according to the procedures of the ISO 527-2. A Testometric universal testing machine (model 0500-10084) was employed. A 50.0 KN head load with 10.0 kN pretension and a 50 mm gauge length were used in these tests. The speed was fixed at 50 mm/min.

7.1.1. Un welded Pipe

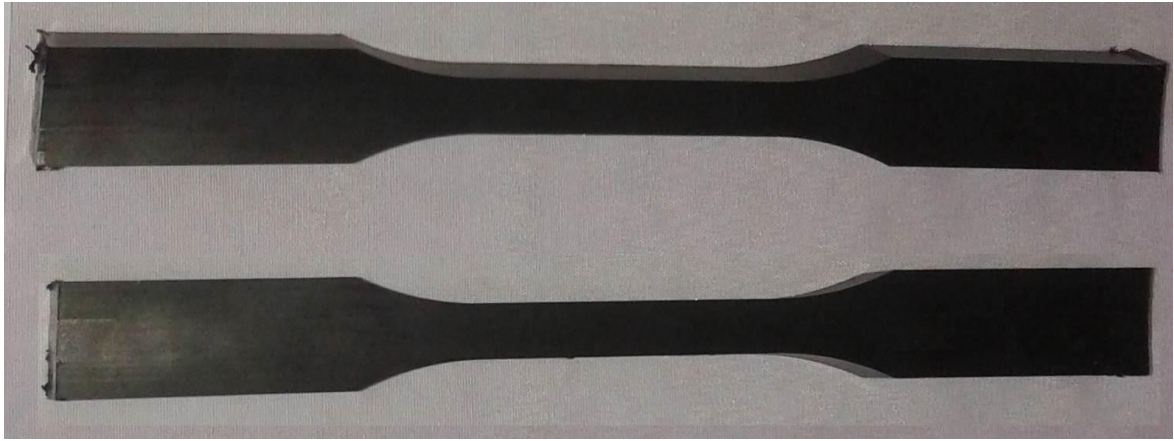
First the experimental tensile test results of un welded pipe *HDPE100RC* according to the dimensions given in sections 6.1.1, 6.1.2 and 6.1.3. These were obtained at end of the experiment are given in Figures 7.1, 7.2. and 7.3. The stress (σ), strain (ϵ) and elongation of break (ΔL) were all measured. Two samples were tested at each step and the average rates were considered and noted.

The tensile test employed *ANSYS* software program for the numerical analysis. The *ANSYS* software analyzed data of un welded and BFW tensile test of *HDPE PE100RC* which node number is 7898 and element number is 1484. This type of element is *SOLID 186* as in Figure 7.4. the numerical material behavior of the pipe is employed as nonlinear, inelastic, rate independent isotropic hardening plasticity, multilinear.

Boundary condition end side of sample is applied right end left $U_x=U_y=U_z=0$ (fixed), but side of sample is applied $U_y = U_z = 0$ and $U_x = 50$ mm.

Multi linear material behavior data is obtained from un welded tensile test result. A Yong modulus is 960 MPa and Poisson ratio is 0.4. The typical stress strain diagram of PE materials as shown in Figure 7.3. The results show as a having negative slop.

Finally after getting the numerical result and then after comparing it is with the experimental data of stress and strain for un welded pipe as shown in Figure 7.5. The mechanical behavior of the HDPE un welded as in Table 7.1

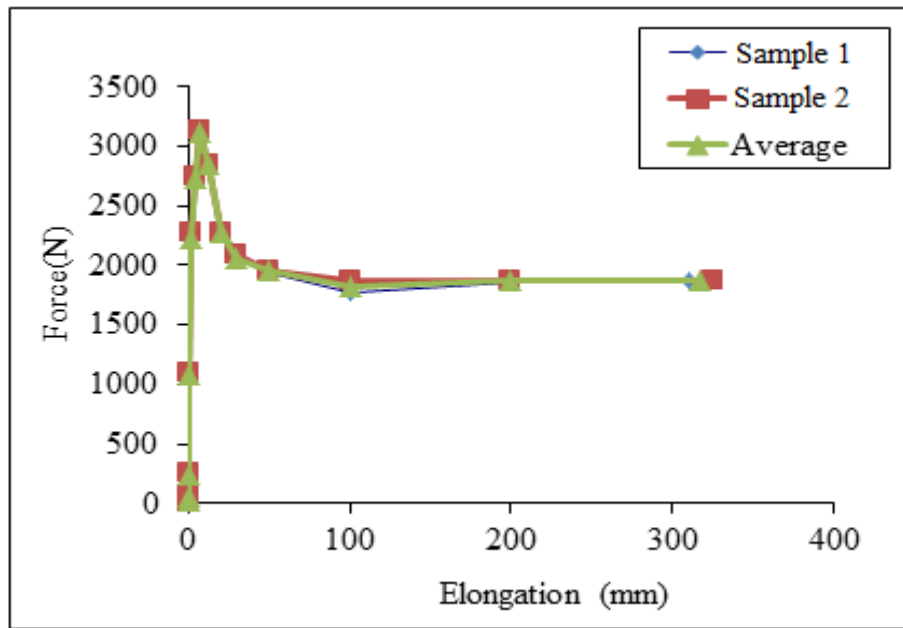


a)

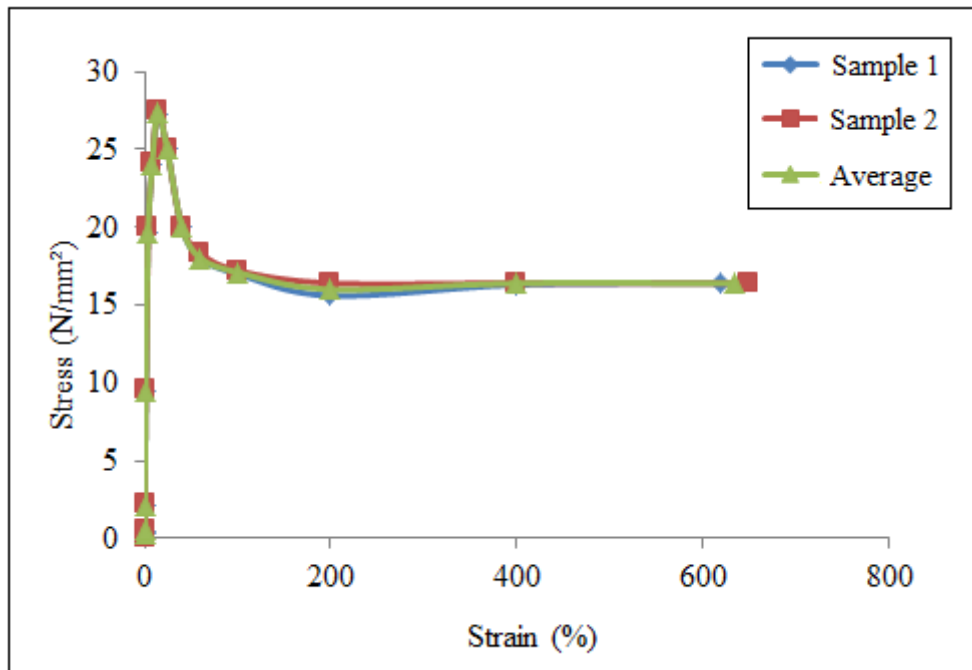


b)

Figures 7.1. The un welded *HDPE PE100RC* tensile test sample a) before testing and b) after testing.



a)



b)

Figure 7.2. The experimental results of un welded pipe *HDPE PE100RC* of two samples with average of them a) force and elongation and b) stress and strain.

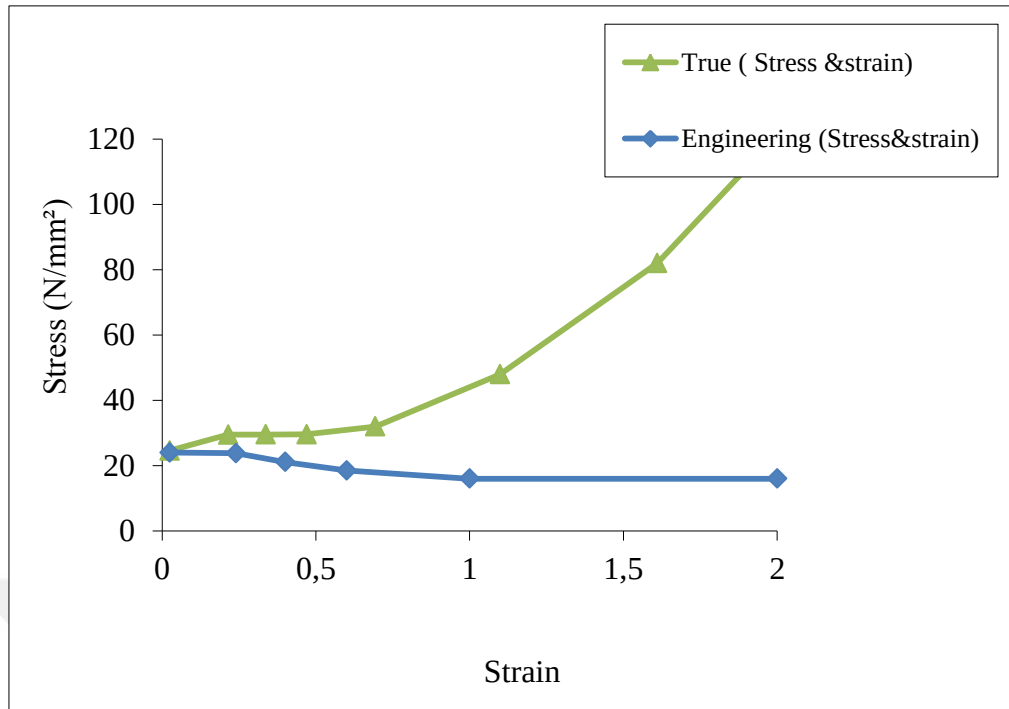


Figure 7.3. The experimental results of un welded pipe *HDPE PE100RC* showing the true stress and true strain with engineering stress and strain.

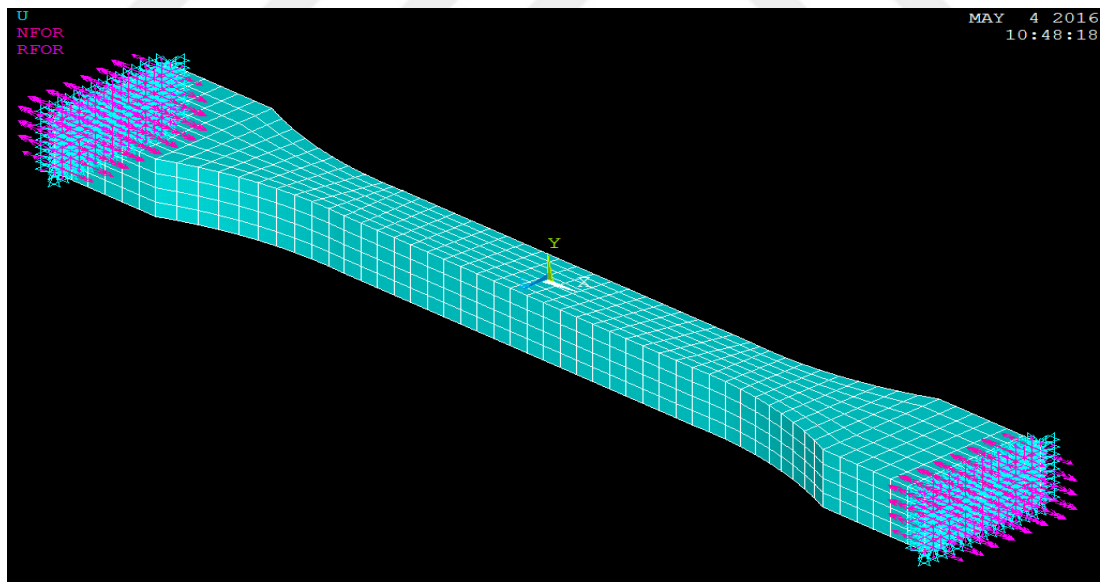


Figure 7.4. Tensile test of un welded *HDPE* sample element type and putting load on sample.

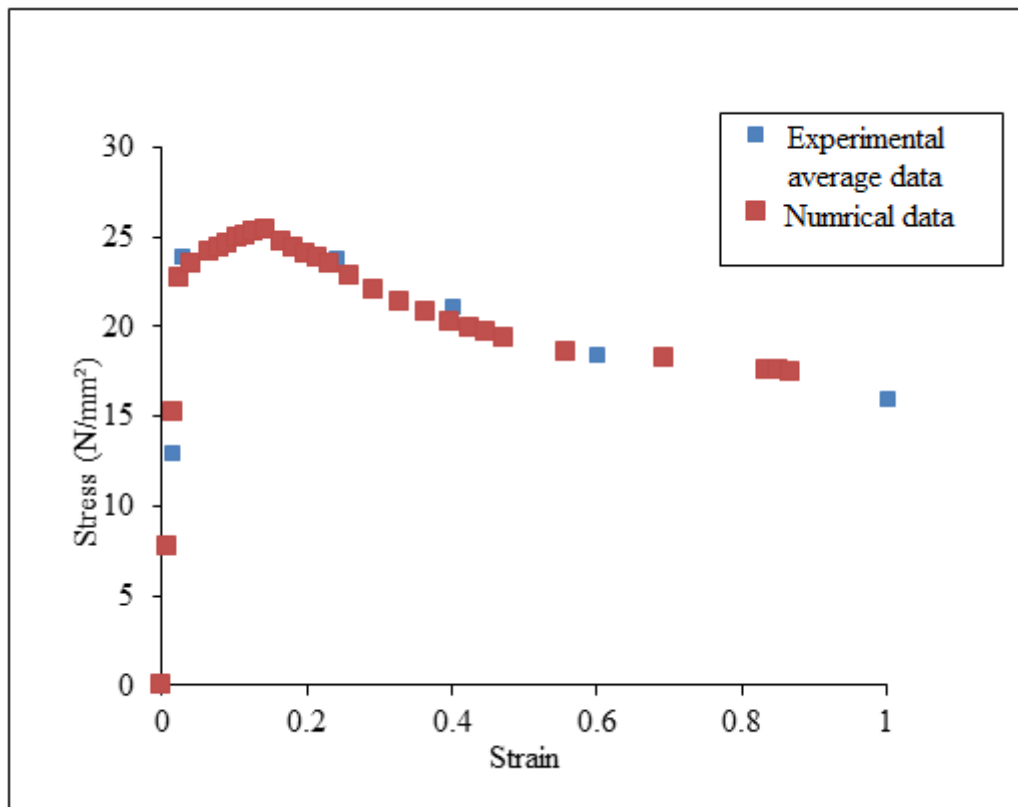


Figure 7.5. Comparing result of experimental and numerically for un welded samples relation between stress and strain.

Table 7.1. Mechanical properties of un welded *HDPE PE100RC*.

Test No	F _{max} (N)	F _{elastic} (N)	Strain (ε) %	Elongation at break (ΔL) (mm)	Youngs Modulus (E) (MPa)
1	3109	1680	620	310	955
2	3135	1690	650	325	965
Average	3122	1685	635	317.5	960

In the comparing the final data results between the experimentally and numerically as noted in the graph between the stress and strain for un welded *HDPE* pipe *PE100RC* appear have minimal difference between them. It is because of the calibration of the instruments. The failures are ductile condition with overall good result. These results were obtained for un welded tensile test samples that include the maximum average force is 3122 N, an average elastic force 1685 N, elongation at fracture 317.5 mm and young modulus average is 960 MPa.

7.1.2. BFW

The experimental tensile test results of welded pipe BFW according to the dimensions given in section 5.1.1 and 5.1.3. With the obtained results shown in Figures 7.6 and 7.8. The stress (σ), strain (ϵ) and elongation at break (ΔL) were measured. Two samples were tested at each step with the average rates were considered. The results of the tests show, that change of elastic material properties inside the polyethylene weld can be found [56]. The indentation modulus is highest in the center of the weld joint and decreases with in proximity to basic pipe material. The material inhomogeneity presented in the weld can be modeled based on a functionally graded material (FGM) [56] and taken into account in subsequent numerical calculations. Based on experimental experiences, the distribution of Young modulus across the weld $E(z)$ can be applied into the numerical model using the double power-law function as follows [57]:

$$E(z) = h1E_{max} + [1 - h1(z)]E_{min} \quad \text{for } 0 \leq Z \leq \frac{W}{2} \quad (7.1. a)$$

$$E(z) = h2E_{max} + [1 - h2(z)]E_{min} \quad \text{for } \frac{W}{2} \leq Z \leq W \quad (7.1. b)$$

Here the functions $h1(z)$ and $h2(z)$ are:

$$h1(z) = \frac{1}{2}(z^p)(w/2)^p \quad \text{for } 0 \leq Z \leq \frac{W}{2} \quad (7.2. a)$$

$$h2(z) = 1 - \frac{1}{2}(w - z)^p(1/0.5w)^p \quad \text{for } \frac{W}{2} \leq Z \leq \frac{W}{2} \quad (7.2. b)$$

The exponent p describes the change of material properties and w represents the half-width of the weld bead. Using the expression in Eqs. (7.1) and (7.2) the change of Young modulus $E(z)$ can be easily parameterized when the ratio E_{max}/E_{min} is known. An experiment has been performed [56] for polyethylene (PE100RC used in this study) see Figure 7.7.

The values were further extrapolated by the double power law function (Eqs. (7.1) and (7.2)) where the half width of the weld was chosen as $w = 7$ mm with the exponent of $p=2$. The ratio E_{max}/E_{min} for HDPE ($E_{max}/E_{min} = 1.1$). For analyzing, the experimental

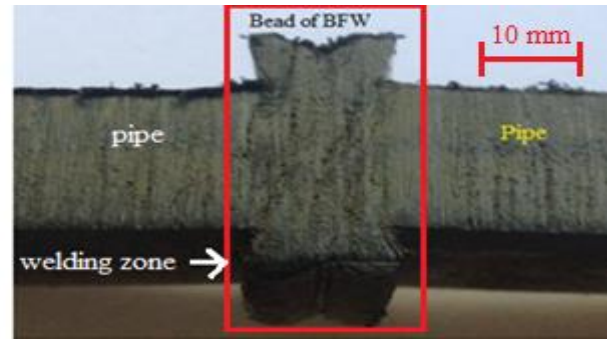
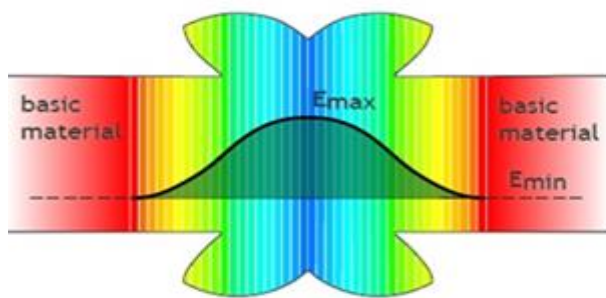
data by employed ANSYS for BFW after removing the bead weld of the tensile test sample of the models, element type and node number are the same as the un welded numerical analysis in section 7.1.2 .

For the numerical analysis the same geometry, boundary and mesh size like un welded sample was used. The only difference between the BFW and the un welded material model was the welding zone. The obtained results of tests shows that material properties change across the weld length for BFW zone for material inhomogeneity ($E_{max}=1.1 E_{pipe}$). By using the equation (7.1) and (7.2) variations of the material behavior can be obtained as in Figure 7.7. And also by numerically analysis show as in Figure 7.9. The comparison finally result between experimentally and numerically as in Figure 7.10. And the mechanical behavior of the BFW as in Table 7.2.

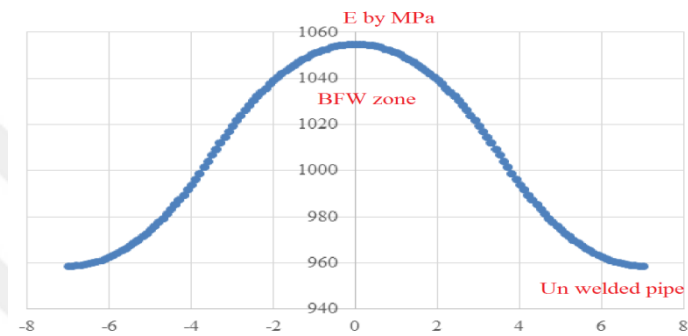


Figures 7.6. BFW tensile test sample before and after testing.

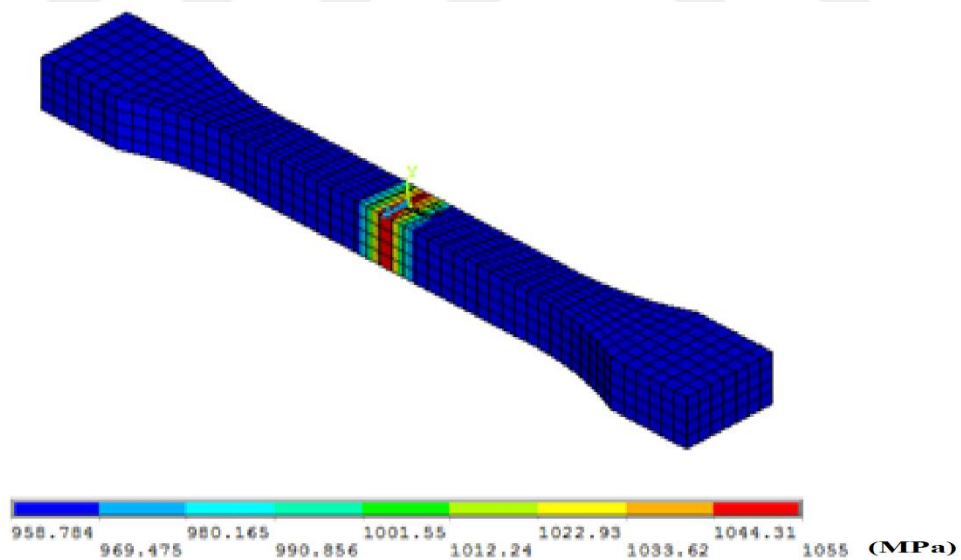
As ANSYS does not offer variation in assigned material properties across elements directly, the material property gradient is applied via a spatial variation in assigned nodal temperatures. As the finite element formulation leads to an interpolation of temperatures within the elements, this results in a continuous variation in properties. Therefore gradient of material properties for FGM are defined as a function of temperature with the help of a subroutine prepared by using APDL codes. Then the Young modulus is defined as a linear function of temperature and the coefficient of thermal expansion is set to zero to avoid the presence of thermal residual stresses. So it is provided that meaningful property of temperature does not physically remain and second order variation of material properties *Young modulus* is defined with using temperature.



a)

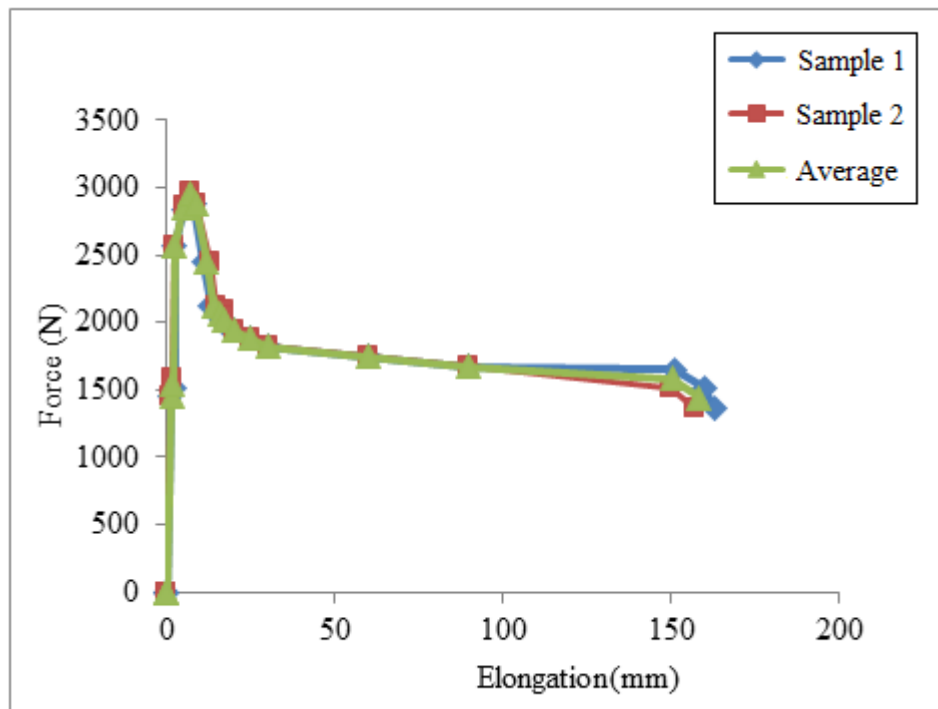


b)

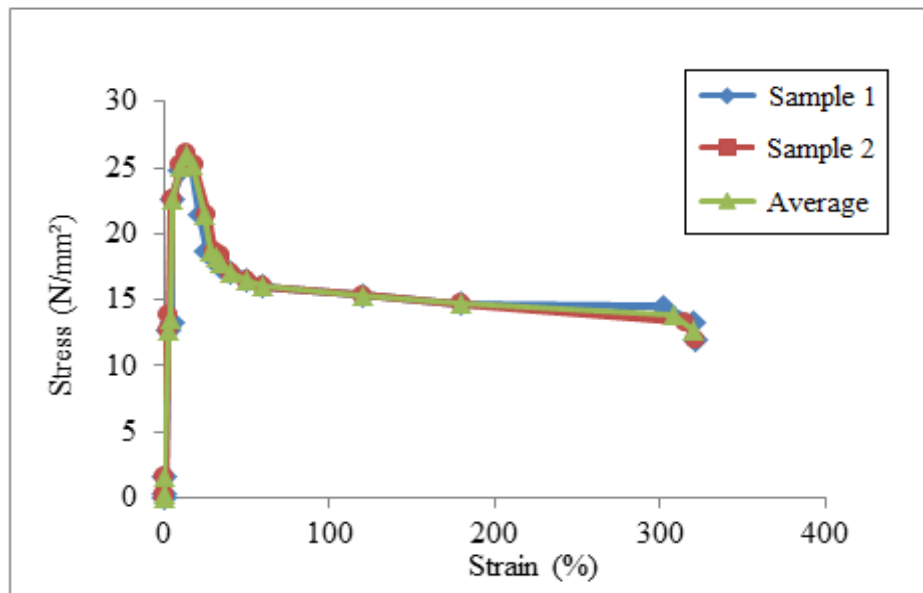


c)

Figure 7.7. a) Bead weld in the BFW zone and b) young modulus of elasticity between welded zone and un welded zone for BFW c) numerical model of functionally graded material.



a)



b)

Figure 7.8. Experimental results of BFW tensile test of two samples with average of them
a) between force and elongation and b) between stress and strain.

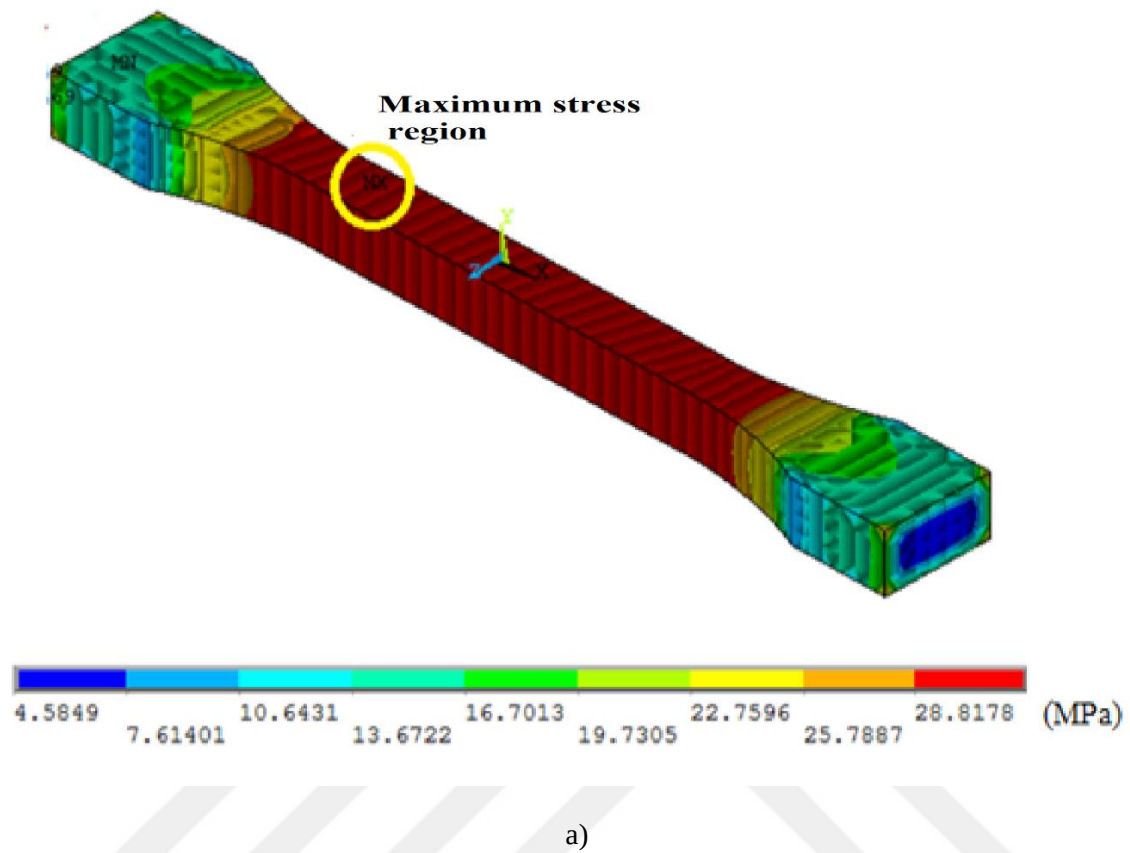


Figure 7.9. a) Equivalent stress distribution in BFW sample by numerically b) experimentally failure zone of BFW specimen.

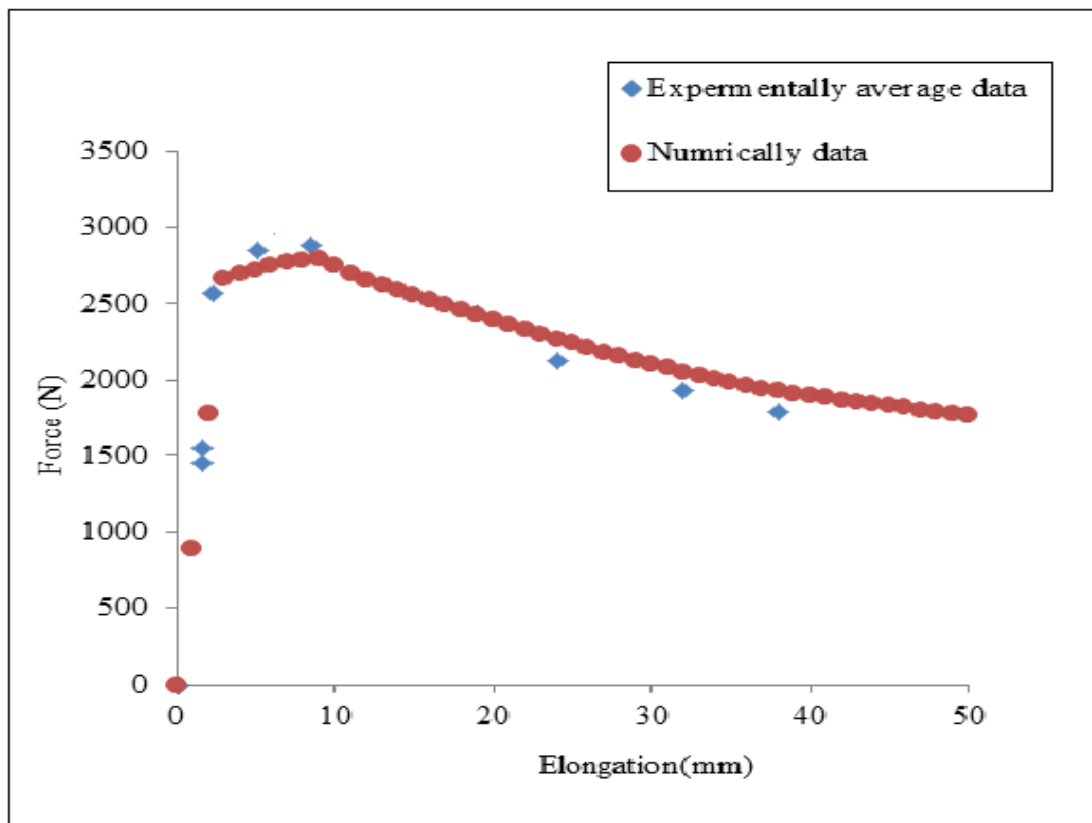


Figure 7.10. Result of relation between stress and strain by experimentally and numerically for BFW welded.

Table 7.2. Experimental results of BFW for HDPE *PE100RC*.

Test No	$F_{\max}$ (N)	F_{elastic} (N)	Strain (ϵ) %	Elongation at break (ΔL) (mm)
1	2998.5	1584.5	348	174
2	2989	1565	345	167.5
Average	2993.75	1574.75	346.5	170.75

The graph in Figure 7.10 is comparing between the result of expementally and numricaly finding the the modulus of elasticity by experimentally and numerically same result of unwelded pipe because of the welding zone in BFW stronger than the unwelded pipe and appearance the ductile failure in the sample.

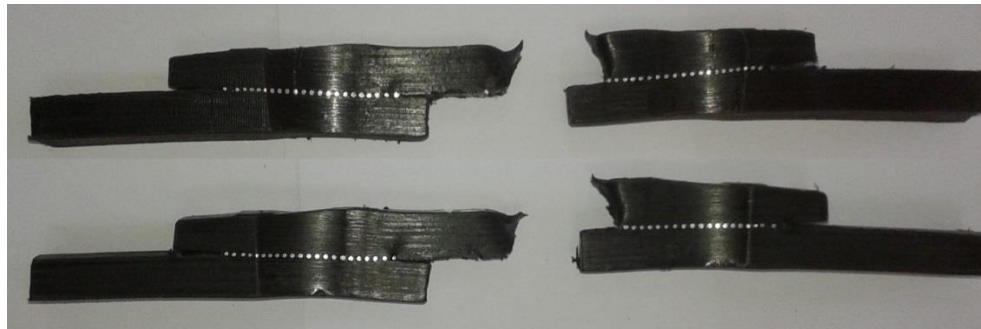
In Table 7.2 the average maximum force is 2993.7 N, the elastic force average is 1574.7 N and the elongation at fracture is 170.7 mm in finally obtained results is like unwelded material behavior and BFW zone shows perfectly material behavior like unwelded HDPE.

7.1.3. EFW

The experimentally tensile test results of welded pipe EFW according to the dimensions in section 6.1.1, 6.1.2 and 6.1.3. The tensile test samples of EFW before and after testing showing as in Figures 7.11. The stress (σ), strain (ϵ) and elongation of break (ΔL) were all measured. Two sample were tested at each step and the average rate were considered. The obtained results of the experimental of the relation ship between force and elongation at the fracture are shown in Figure 7.12 and the relation ship between the stress and percent strain are shown in Figure 7.13.



a)



b)

Figure 7.11. EFW tensile tests sample a) before and b) after testing.

Using the ANSYS program for analyzing EFW tensile test in the study getting node number is 4107 and element type is *SOLID186* with element number is 1484 as in Figure

7.14. and compared results between experimentally and numerically for the force and elongation relationships are shown in Figure 7.15.

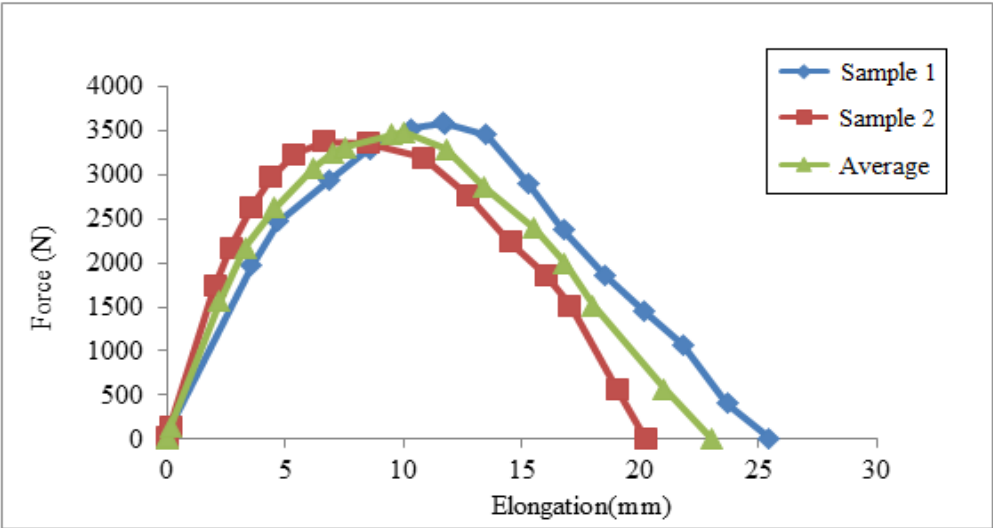


Figure 7.12. Experimental results relation between force and elongation of EFW in HDPE PE100RC of two sample with average of them.

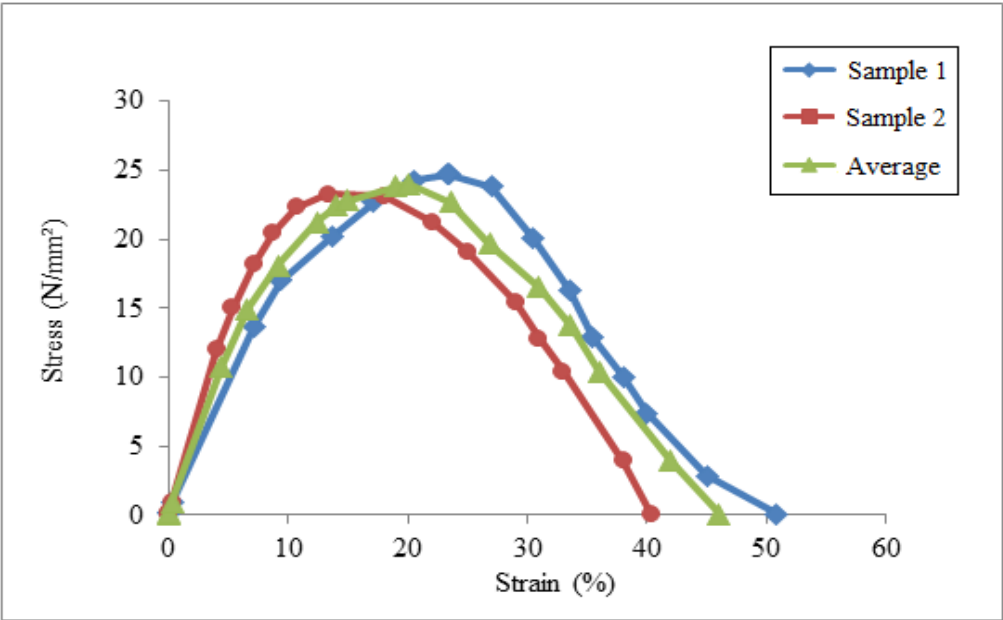


Figure 7.13. Experimental results relation between stress and strain of EFW in HDPE PE100RC of two sample with average of them.

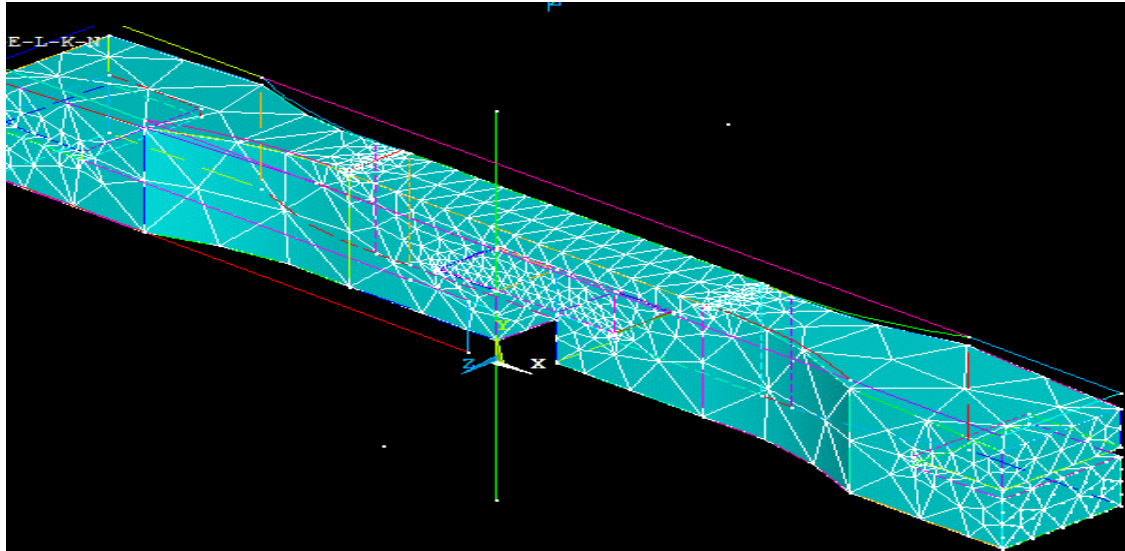


Figure 7.14. Numerical mesh model of the electro fusion welding model.

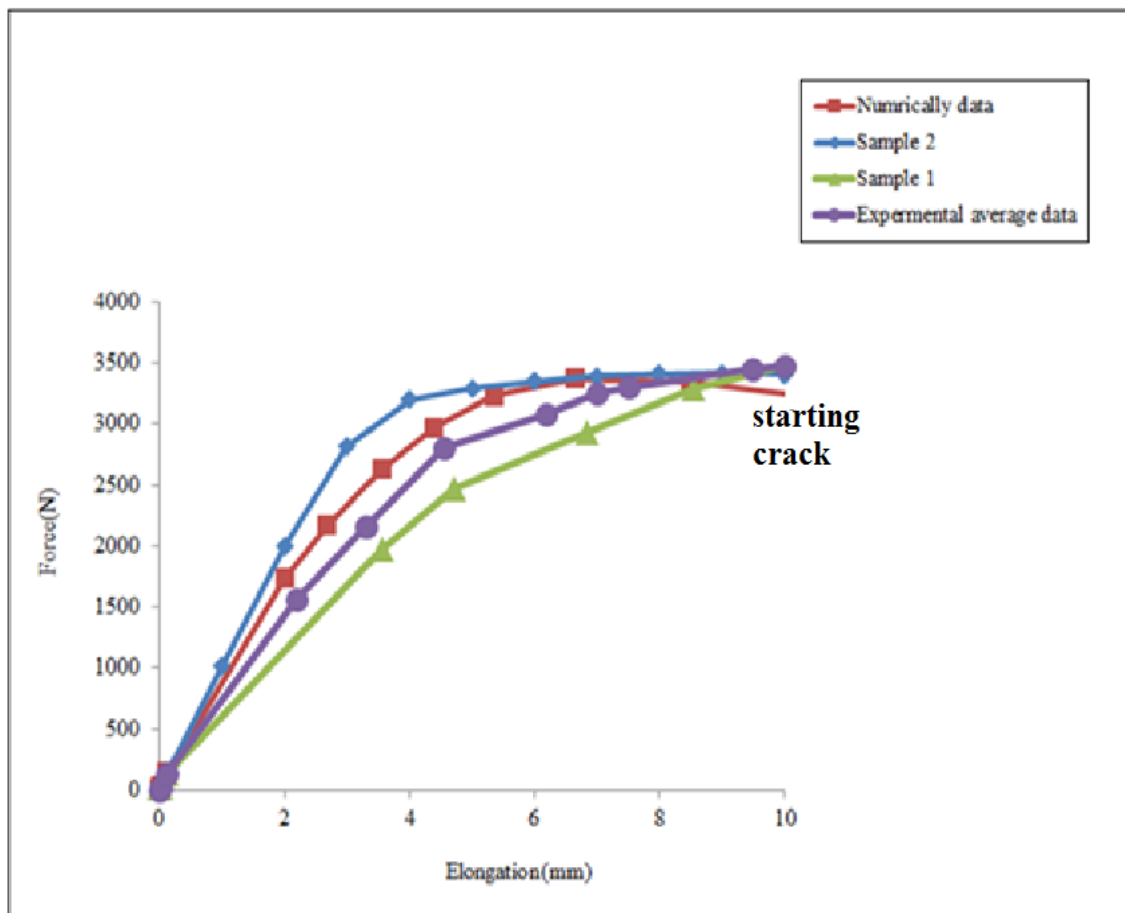
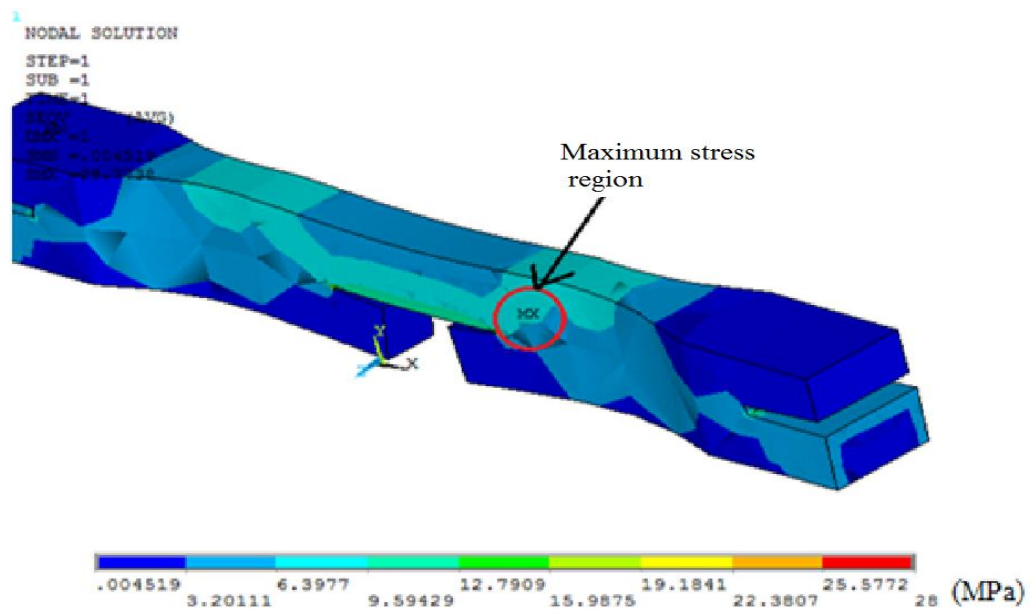
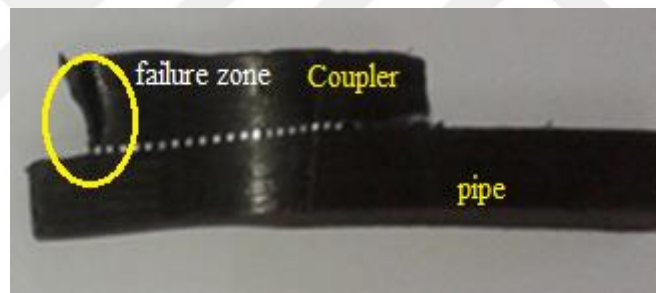


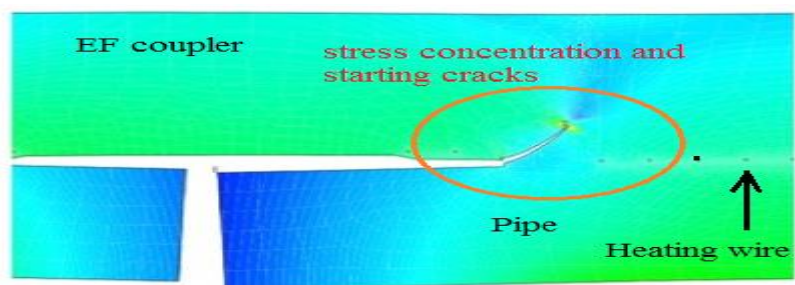
Figure 7.15. Comparing result of force and elongation by experimentally and numerically for welded EFW tensile test.



a)



b)



c)

Figure 7.16. a) Equivalent stress distribution for welded EFW tensile test sample b) Experimentally of EFW sample after testing and b) stress concentration and starting cracks during test of EFW sample [16].

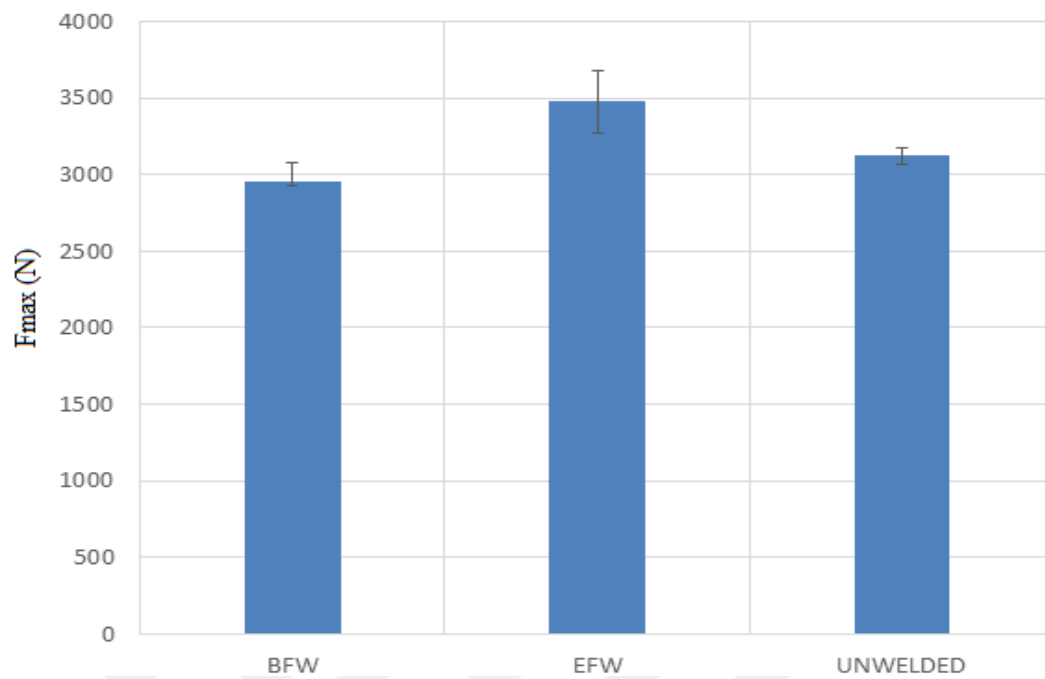
Table 7.3. Mechanical behavior of welded sample (EFW) of HDPE PE100RC.

Test No	F _{max} (N)	F _{elastic} (N)	Strain (ϵ) %	Elongation at break (ΔL) (mm)
1	3513	1969	51	25.44
2	3477	1737	40.4	20.2
Average	3490	1853	45.5	22.82

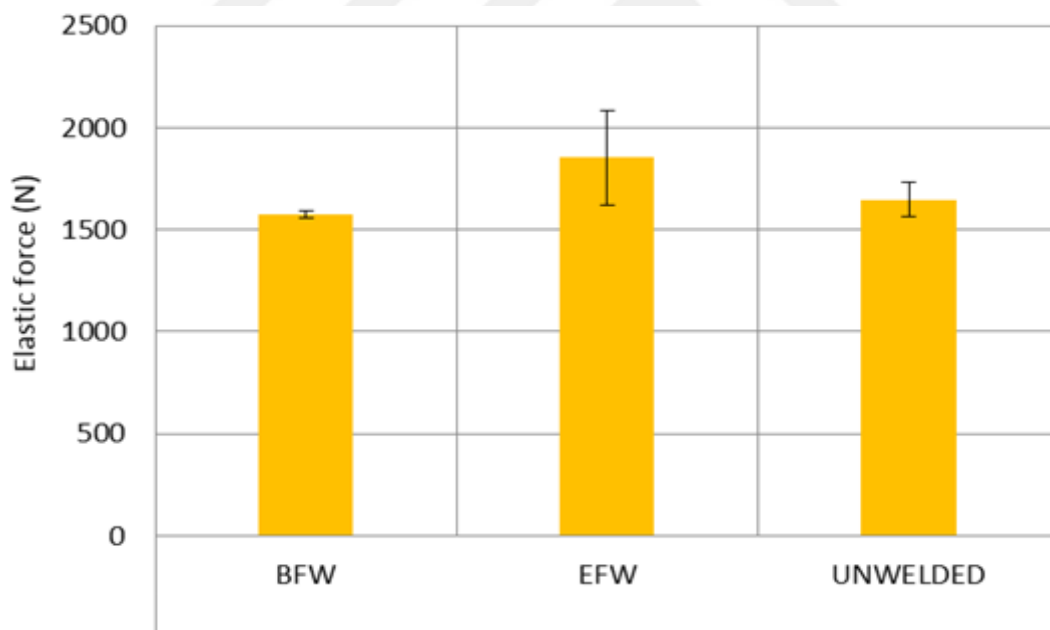
The result of the experiments appear failure ductile when comparing the data result between the experimentally and numerically in the finally showed the graph between the force and elongation for welded EFW in HDPE PE100RC. It have less difference between them, which it is because of maintenance and calibration of the machine test. The obtained result in this study shows the average maximum force is 3490N , the average elastic force is 1853N and the elongation at fracture is 22.83 mm.

In the graph between the force and elongation at fracture appear failure happen during the graph receive the critical point and the starting to down it is because of stress concentration in the place of the heat affected zone near heating wire as in Figure 7.16. b) and c). It causes because of the heating wire.

The comparing average maximum force and comparing the average elastic force as in Figure 7.17. Then comparing average elongation at fracture as shown in Figure 7.18.



a)



b)

Figure 7.17. a) Compare maximum force between un welded and welded (BFW and EFW) and b) compare elastic force between un welded and welded (BFW and EFW).

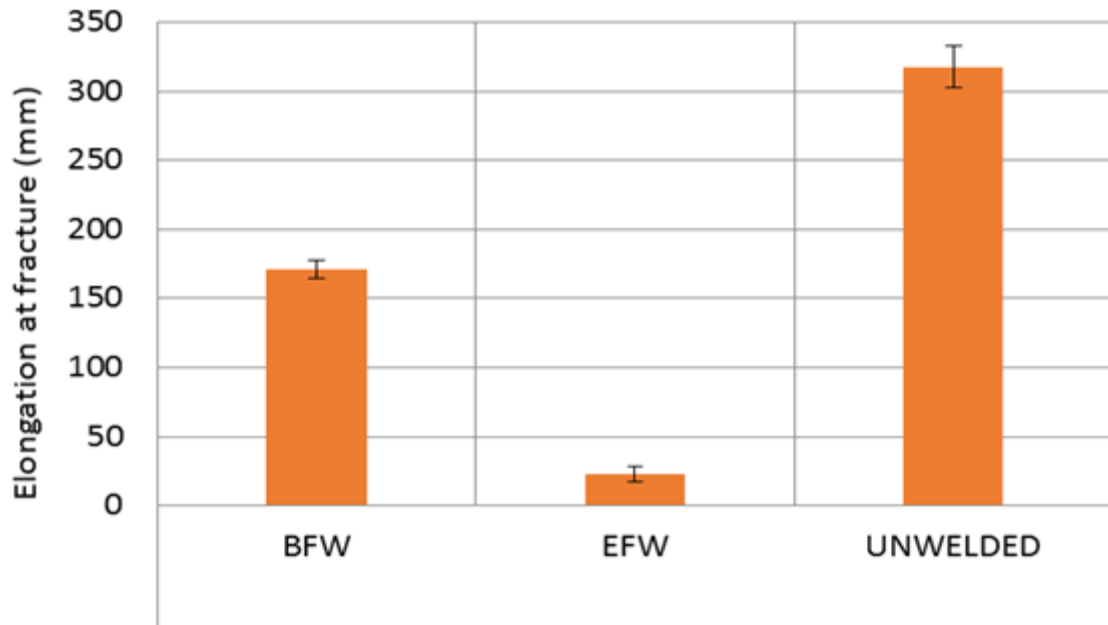


Figure 7.18. Comparing elongation at fracture between un welded and welded both BFW and EFW.

7.2. Tensile Test of Strip

Samples were prepared of the tensile strip. The strip dimensions are noted in section 6.2. A universal testing machine (*Testometric* 0500-10084) was employed. Cracks were obtained with using crack knife as shown in Figure 7.19. A 50.0 kN head load with 10.0 N pretension and 50 mm gauge length was employed for the tests. The speed was fixed at 50 mm/min in HDPE for un cracked and un welded samples as shown in Figure 7.20, 7.21 and 7.22. The un welded cracked samples result are shown in Figures 7.23, 7.24 and 7.25. The BFW un cracked and cracked sample result are shown in Figures 7.26, 7.27, 7.28 and 7.29. The EFW uncracked and cracked sample results are shown in Figures 7.30, 7.31, 7.32, 7.33 and 7.34.

The stress (σ), strain (ϵ) and elongation at break (ΔL) were measured. Two sample were tested at each step and the average rate were considered. The behavior of the HDPE un welded and welded for uncracked and cracked results in Table 7.4 and compared result are in Figures 7.35 to 7.40.

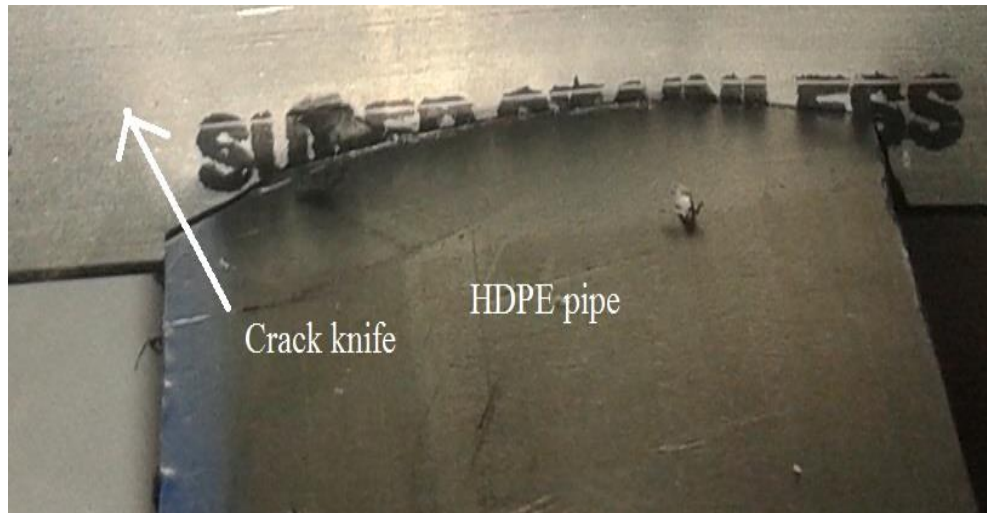


Figure 7.19. The knife on HDPE pipe strip.



Figure 7.20. Tensile strip sample before and after testing.

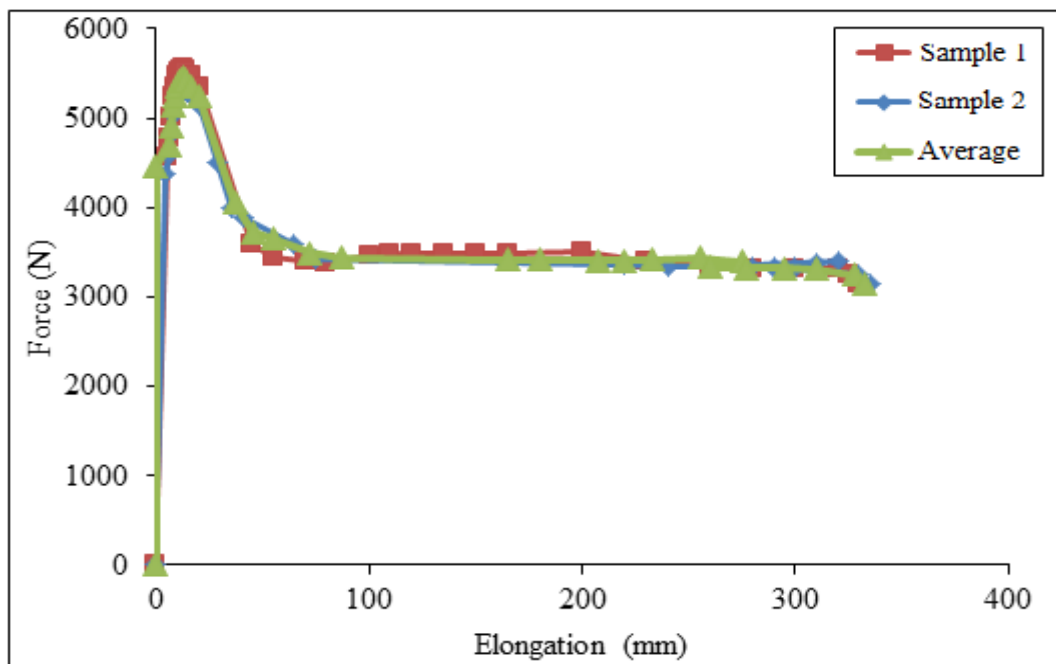


Figure 7.21. Experimental results between force and elongation of un welded HDPE PE100RC of two strip sample with average of them.

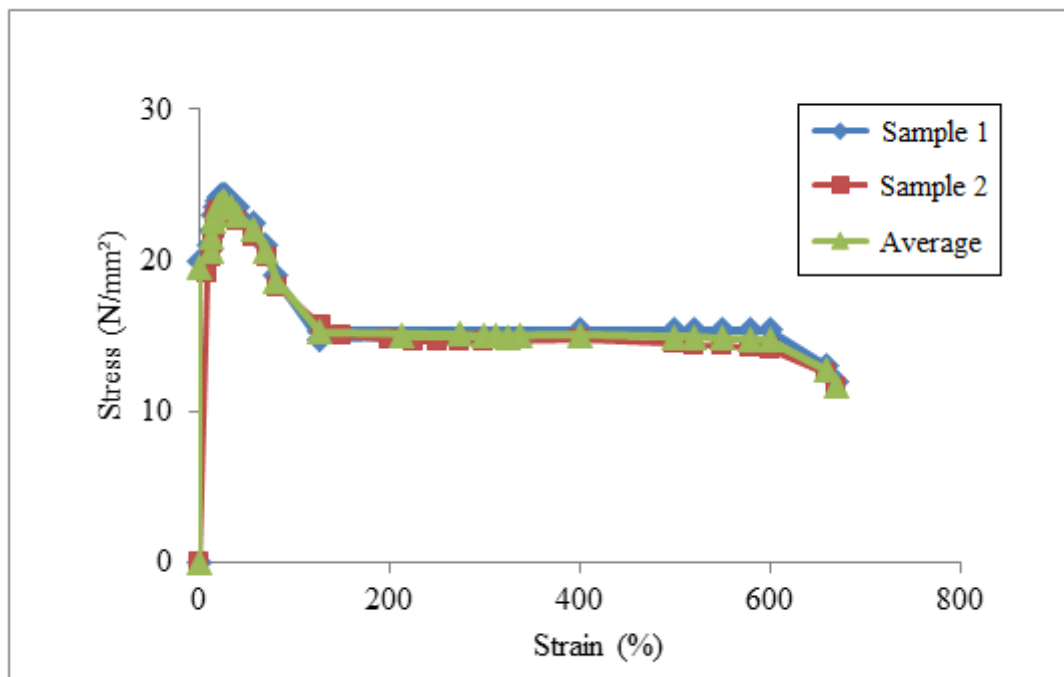


Figure 7.22. Experimental results relation between stress and strain of un welded HDPE PE100RC of two strip sample with average of them.

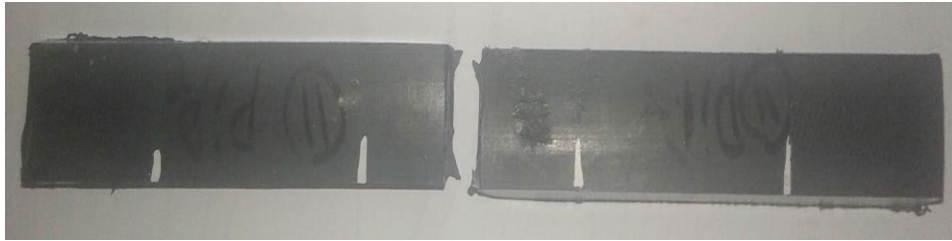


Figure 7.23. With cracked tensile strip sample after testing for un welded pipes.

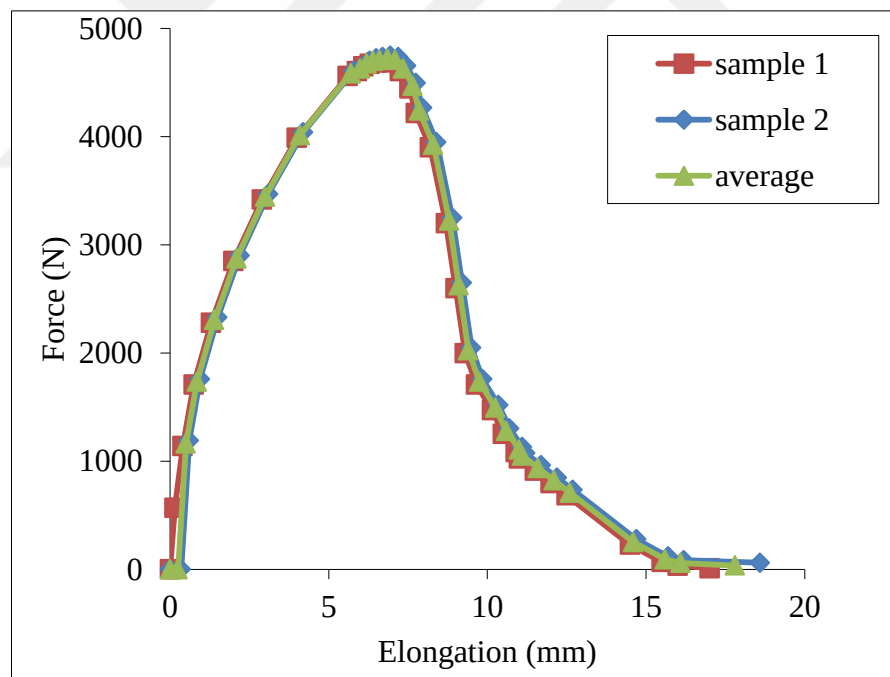


Figure 7.24. Experimental results between force and elongation of un welded HDPE PE100RC of two strip cracked sample with average of them.

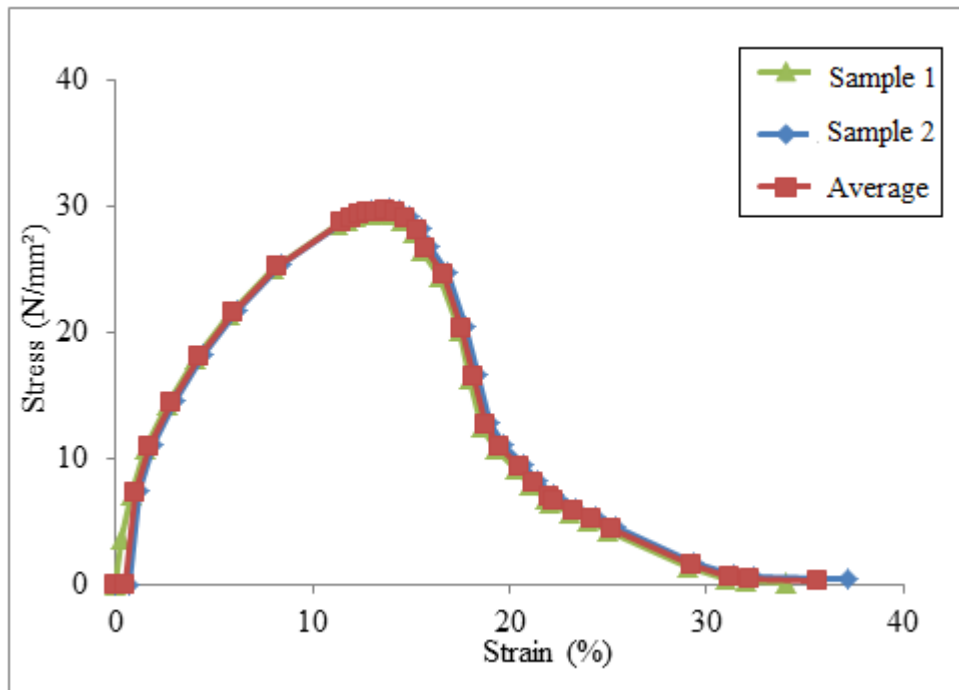
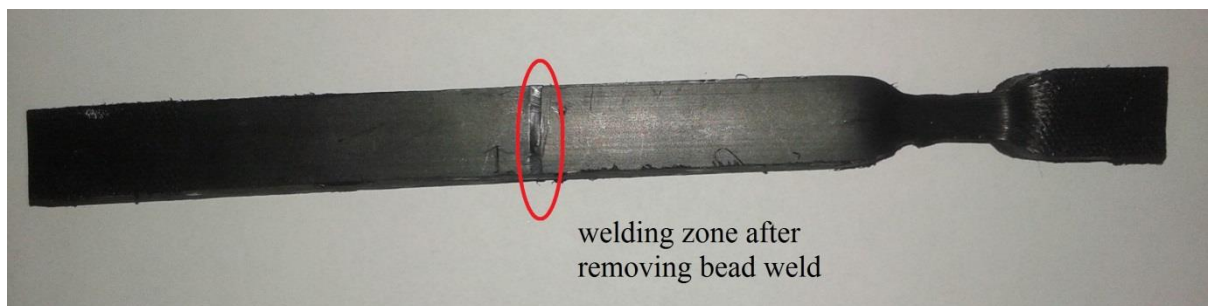


Figure 7.25. Experimental results relation between stress and strain of un welded HDPE PE100RC of two strip cracked sample with average of them.



a)



b)

Figure 7.26. Without cracked BFW sample a) before testing and b) after testing.

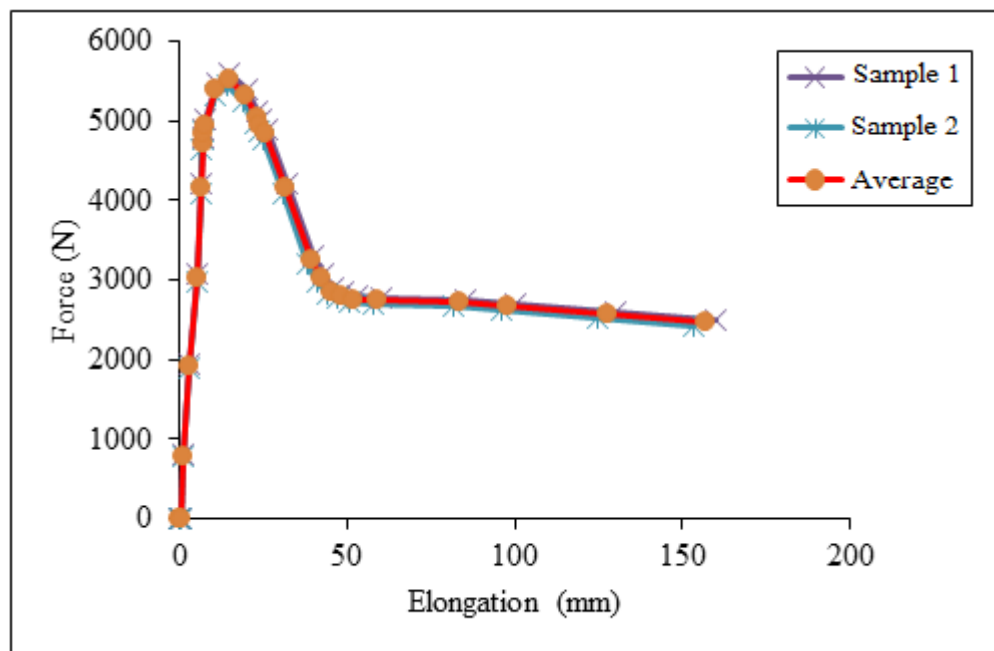


Figure 7.27. Experimental results between force and elongation of BFW welded in HDPE PE100RC of two strip uncracked sample with average of them.

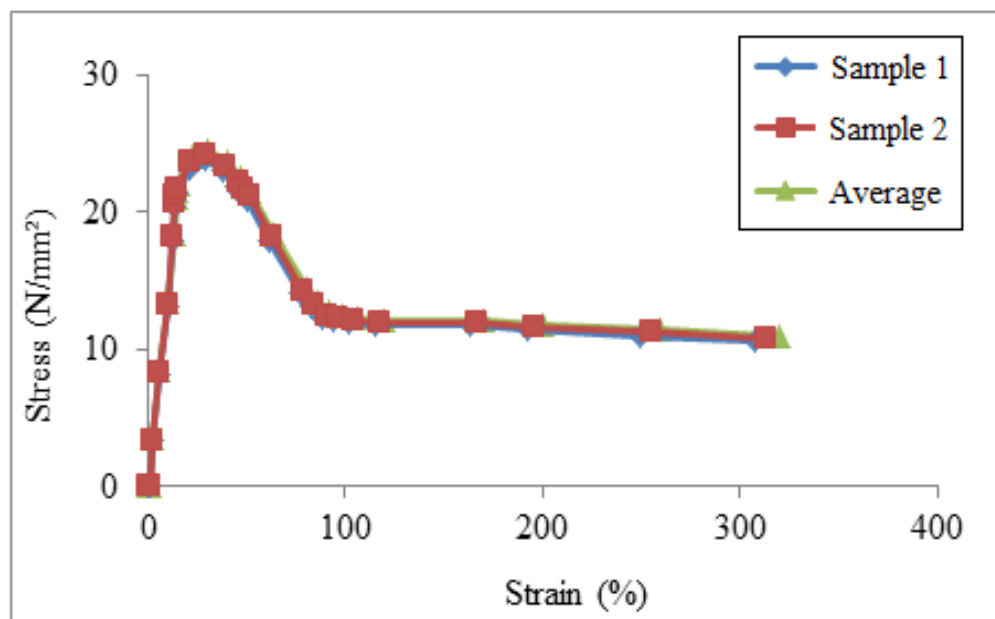
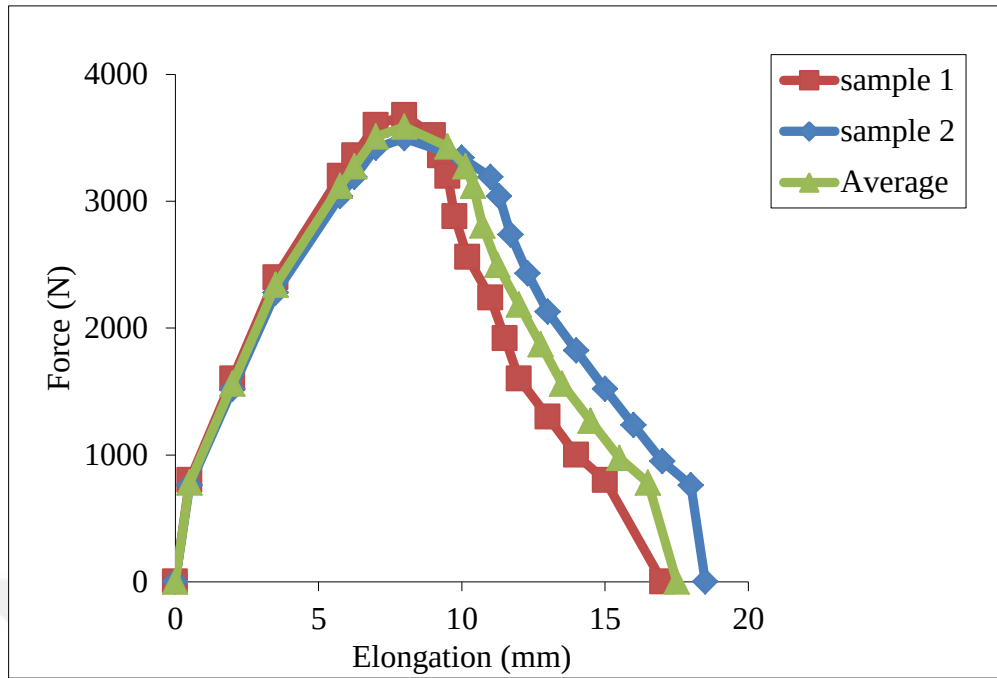
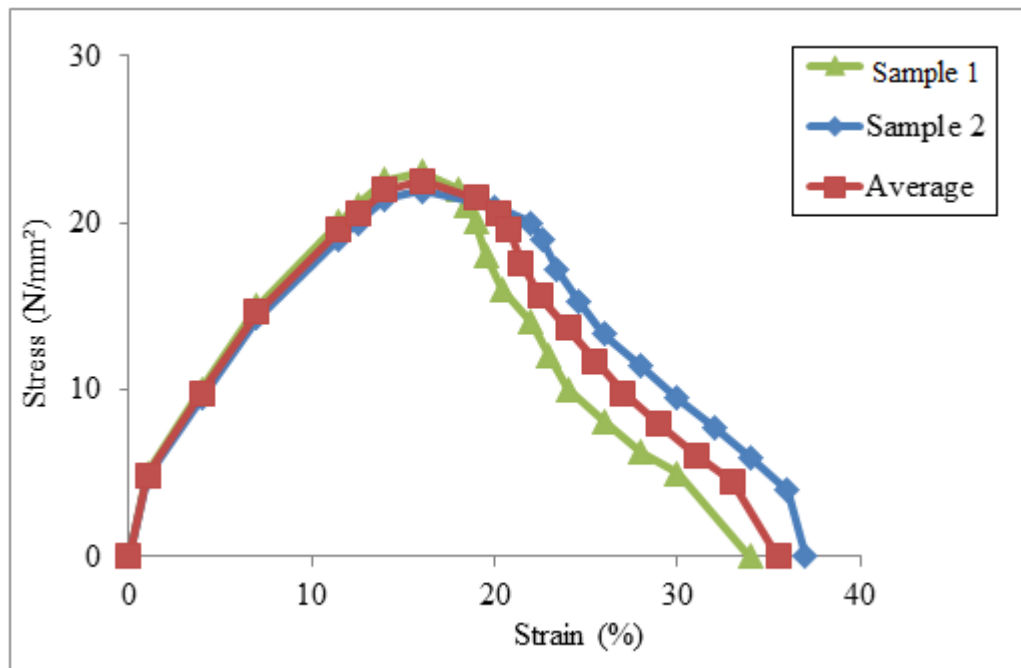


Figure 7.28. Experimental results between stress and strain of BFW welded in HDPE PE100RC of two uncracked strip sample with average of them.

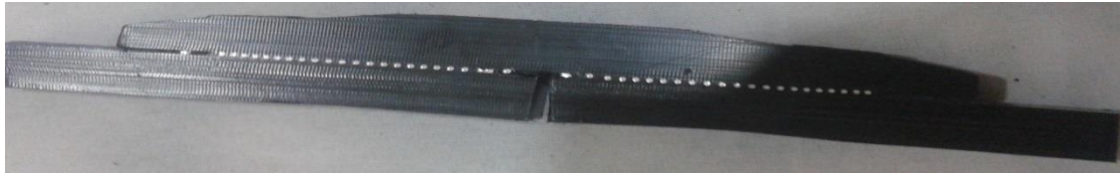


a)



b)

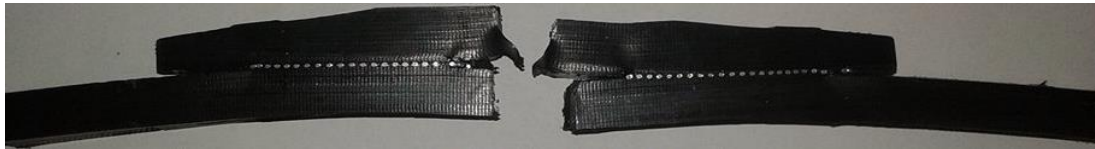
Figure 7.29. Experimental results between a) force and elongation of BFW welded in HDPE PE100RC of two strip cracked sample with average of them and b) stress and strain of BFW welded in HDPE PE100RC of two strip cracked sample with average of them.



a)



b)



c)

Figure 7.30. EFW tensile strip sample a) before testing b) without cracked after testing and c) with cracked after testing.

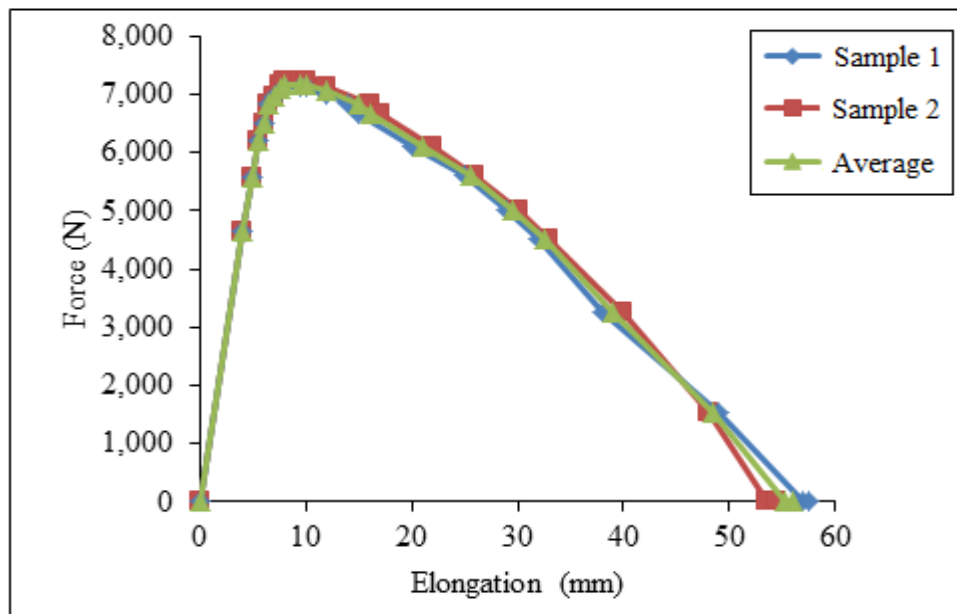


Figure 7.31. Experimental results between force and elongation of EFW welded in HDPE PE100RC of two strip uncracked sample with average of them.

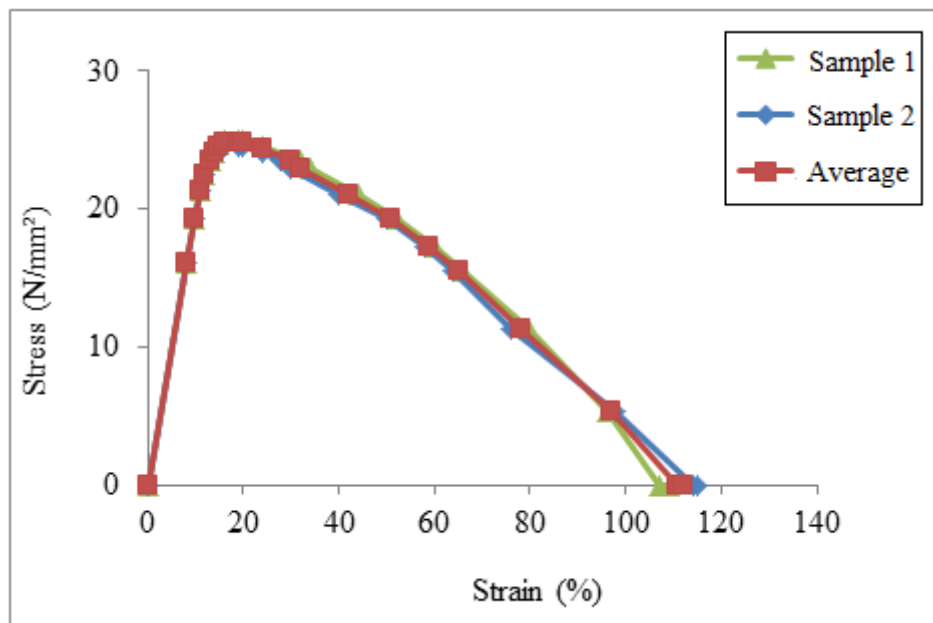


Figure 7.32. Experimental results between stress and strain of FFW welded in HDPE PE100RC of two strip without cracked sample with average of them.

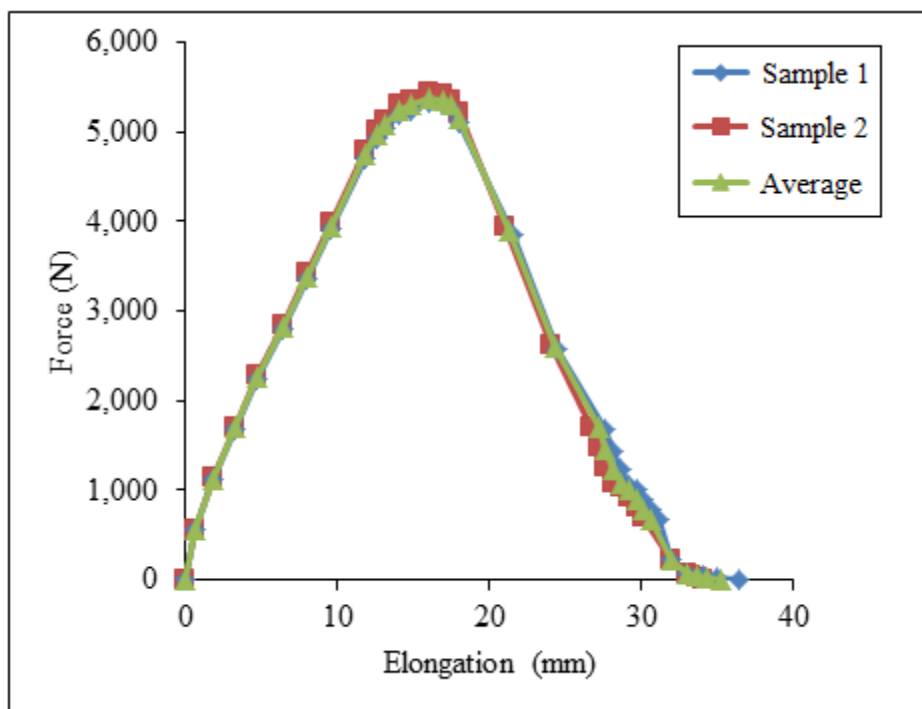


Figure 7.33. Experimental results between force and elongation of FFW welded in HDPE PE100RC of two strip with cracked sample with average of them.

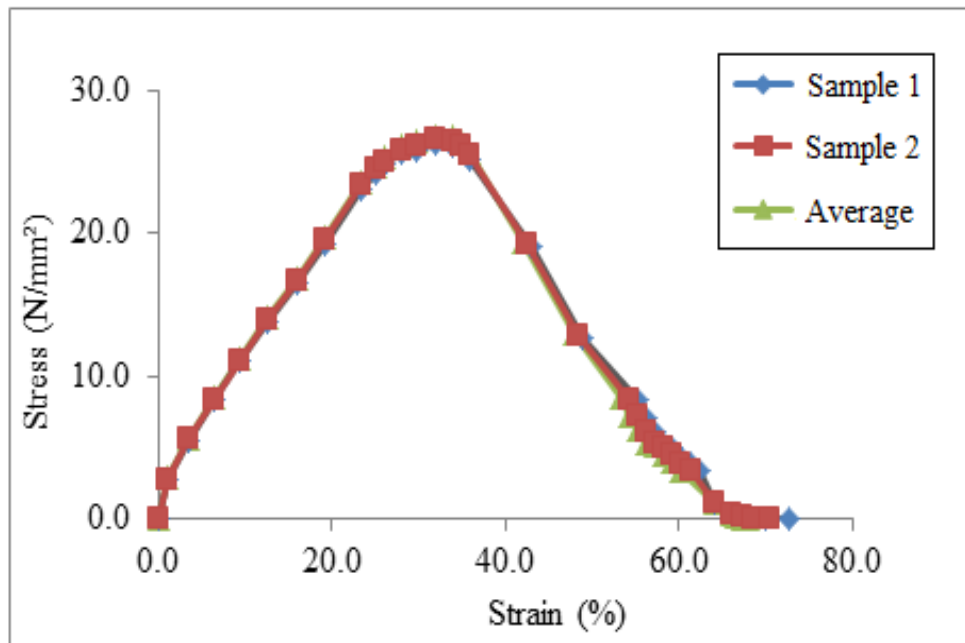


Figure 7.34. Experimental results between stress and strain of FFW welded in HDPE PE100RC of two strip cracked sample with average of them.

Table 7.4. Aveage maximum force, elastic force and elongation at fracture for tensile strip cracked and cracked sample.

	uncracked samples			cracked samples		
	unwelded	BFW	EFW	unwelded	BFW	EFW
Fmax (N)	5451	5322	7177	4696	3581	5383
Felastic (N)	4000	4154	4685	1955	2340	3950
Elongation at fracture (mm)	343	156	53.5	18.5	17.5	17.8



Figure 7.35. Maximum force comparing results of without cracked sample.

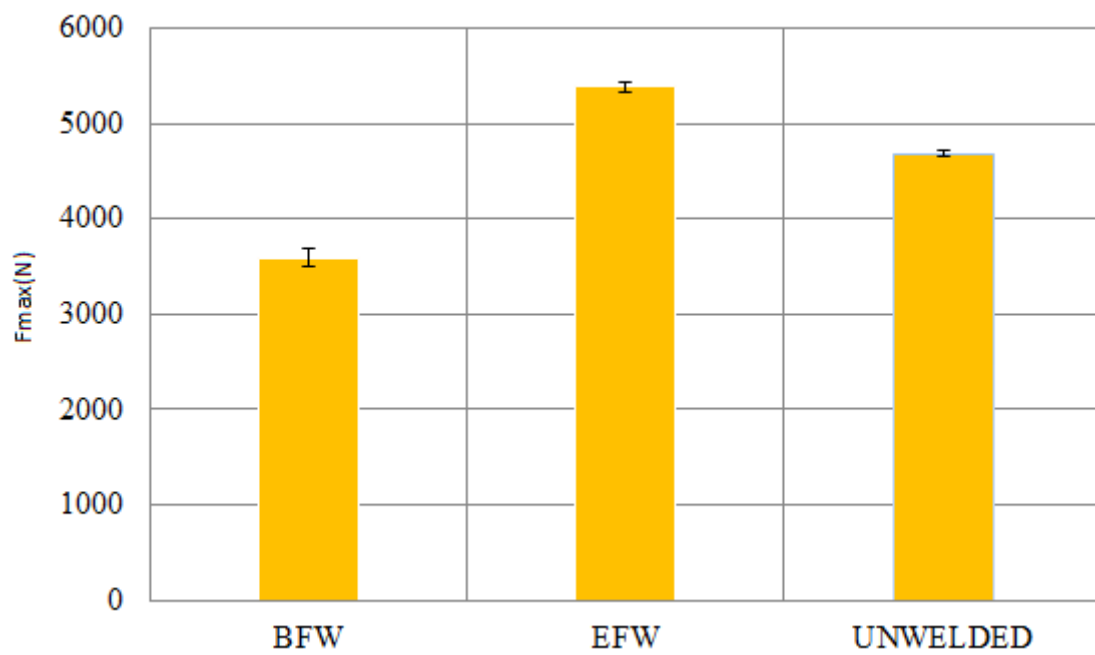
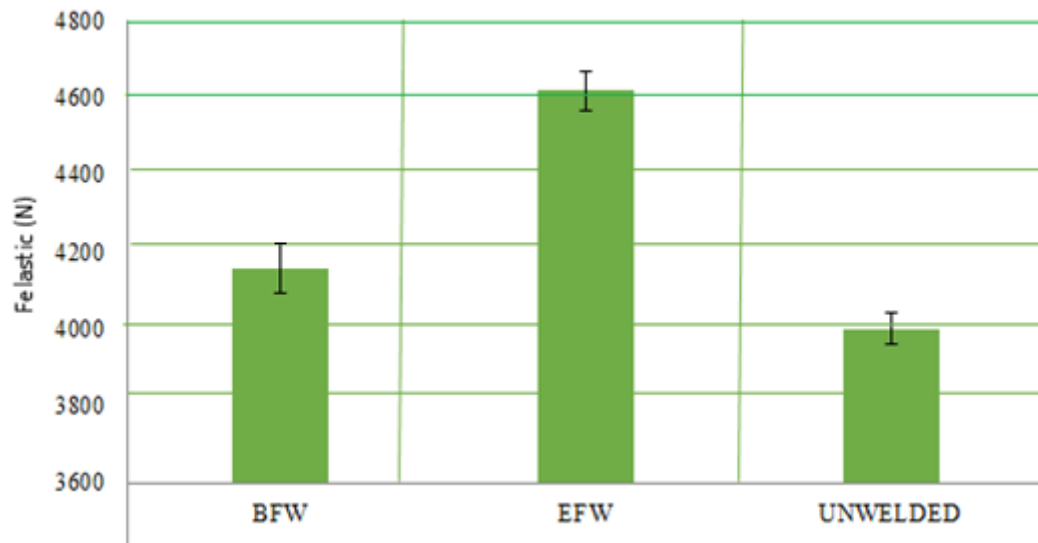
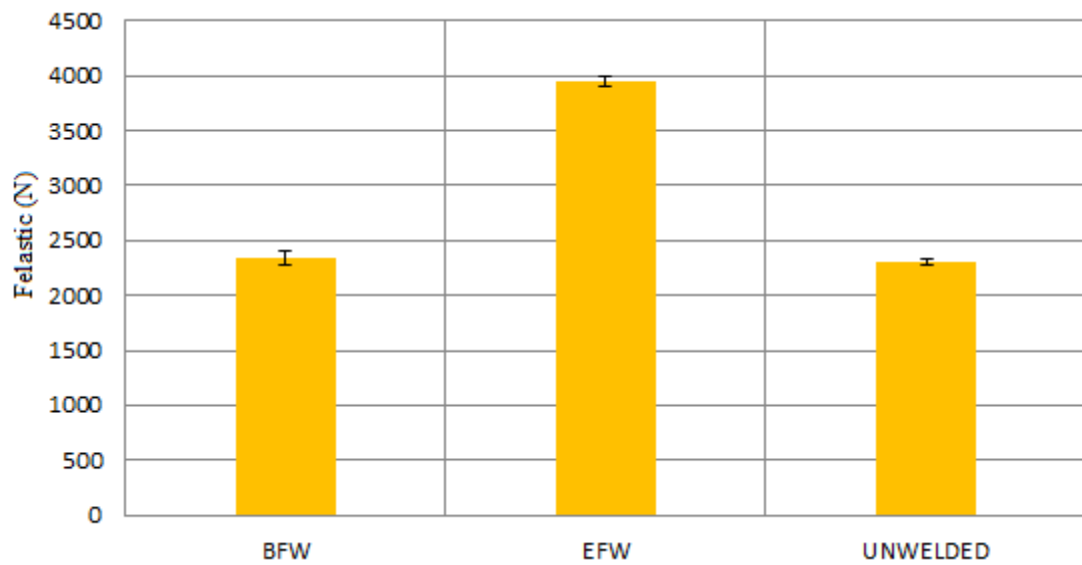


Figure 7.36. Maximum force comparing results of with cracked sample.



Figures 7.37. Elastic force comparing results of without cracked sample.



Figures 7.38. Elastic force comparing results of with cracked sample.

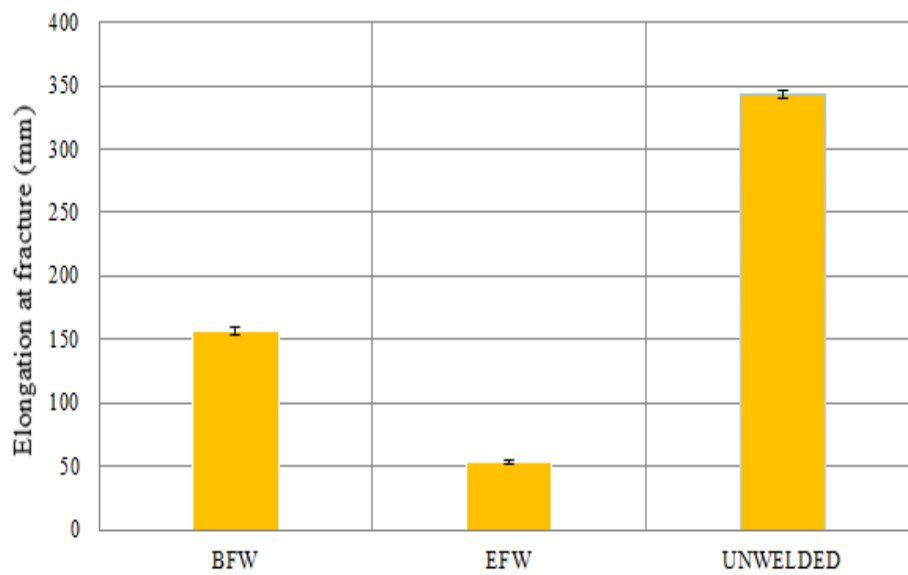


Figure 7.39. Comparing elongation at fracture results of without cracked strip tensile sample.

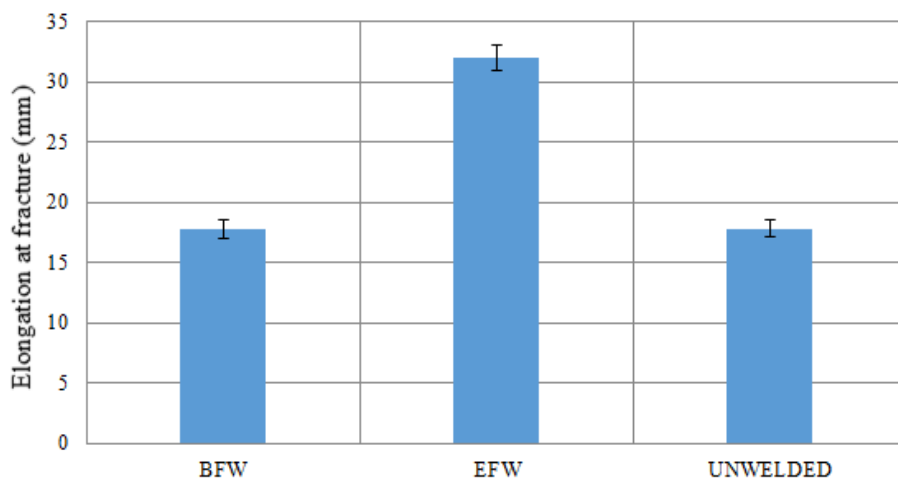


Figure 7.40. Comparing elongation at fracture of tensile strip results of cracked samples.

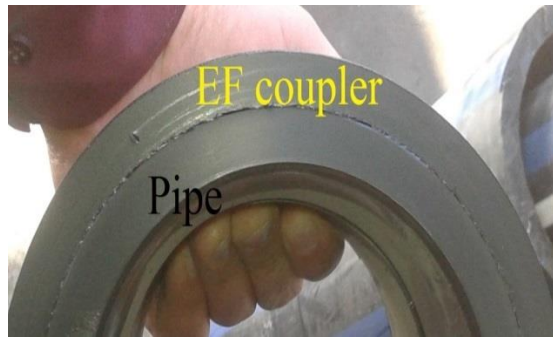
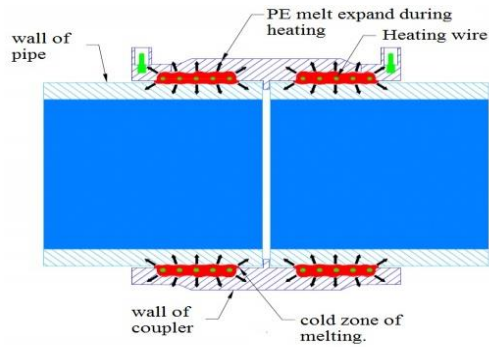
7.3. Hydrostatics Pressure Test

The hydrostatic pressure tests were performed in the Sulimanyah construction laboratories. The procedure of tests were followed according to the international standard ISO as mentioned in section 5.3 for the un welded HDPE pipes and welded (BFW and EFW) of sample by using and without using mechanical performance re-rounding and alignment clamps.

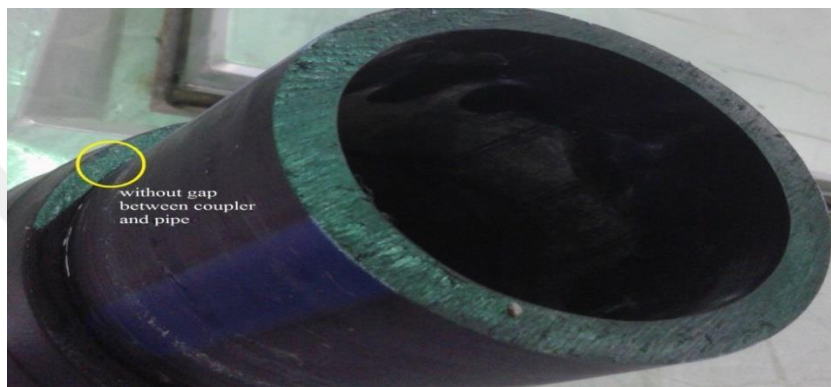
The sample dimensions for un welded and welded samples were prepared as given in section 6.3.1 and then getting the result of that for two sample to each one un welded pipes and welded pipes (BFW and EFW) with and without using performance re-rounding and alignment clamps and the average value were considered. The results of hydrostatics pressure for un welded pipe as in Figure 7.41. For EFW and BFW perfect join have same results of un welded pipe as in Figure 7.42 Because there was no failure within the time limit according to the standard used are shown in Figure 7.41 and 7.42.

The performance result for the EFW and BFW by not using the re roundness and alignment tools during the welding process showed a reduction of the life span of the networking pipe. In Figure 7.43, 7.44, 7.45 and 7.46 shows relation between pressure and time to the EFW sample of hydrostatics pressure of samples whose manufactured achieved without used reroundness and alignmeny.

BFW hydrostatics pressure test samples which was used alignment and re roundness are showed in Figure 7.47 and pressure time graphs are given in Figure 7.48. EFW and BFW hydrostatics pressure results for perfect joint conditions and the same Figure 7.48. Overlap level and pressure test results for BFW are given in Figure 7.50 as pressure/time graph. Obtained total time results for all sample in hydrostatics pressure test are give in Table 7.5



a)



b)

Figure 7.41. a) Expected based on results of examination for electrofusion joints and b) Real sample of EFW after pressure testing which used re roundness and alignment.

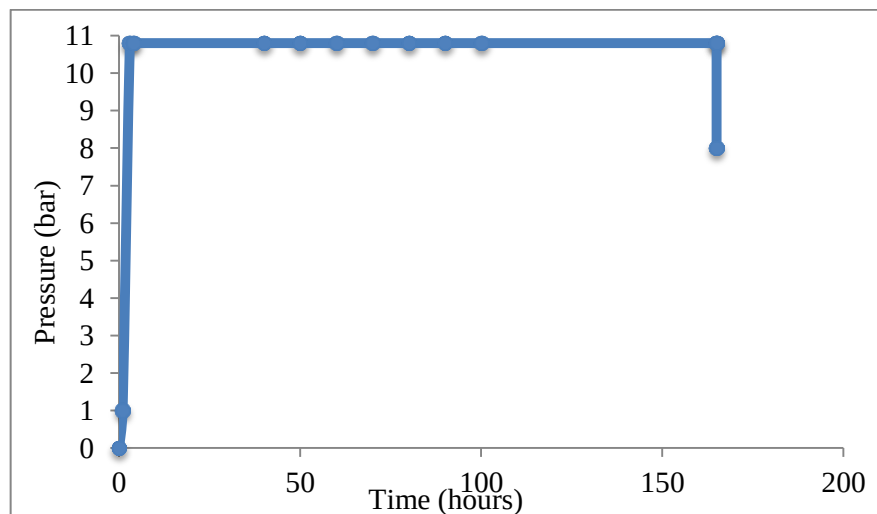


Figure 7.42. The graph between the hydrostatic pressure and time to the HDPE PE100RC sample.

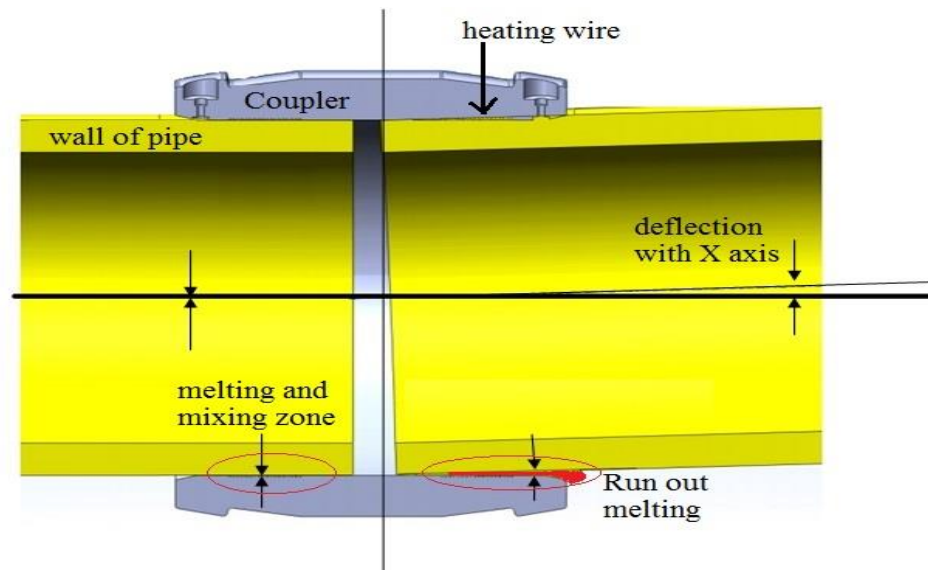


Figure 7.43. Expected image based on result after hydrostatic pressure testing of EFW without using performance of re roundness and alignment.

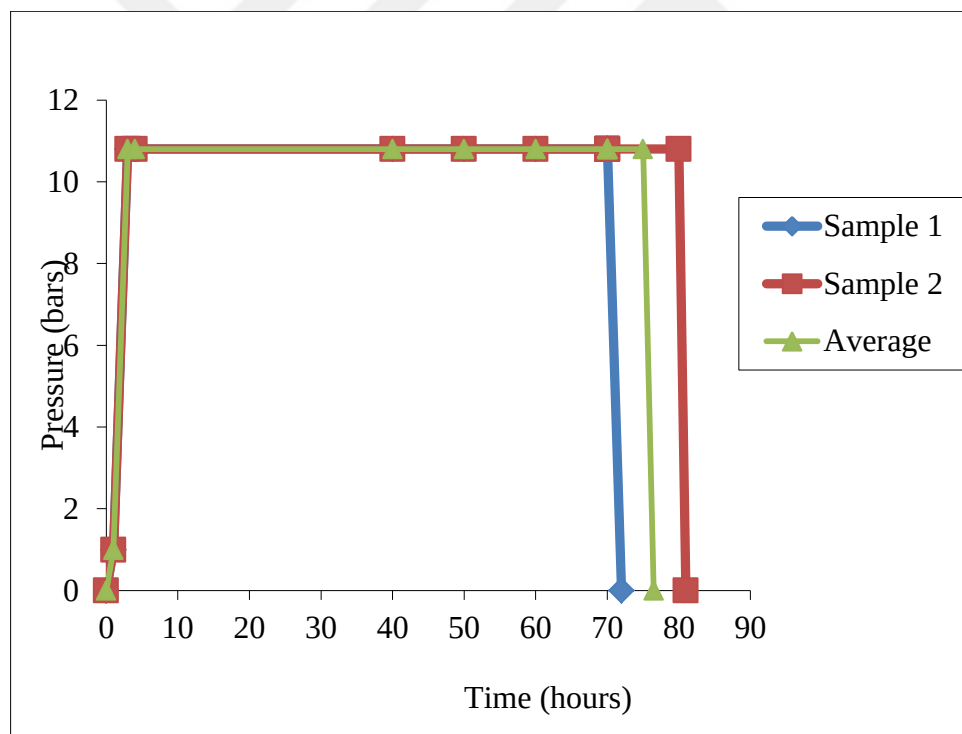
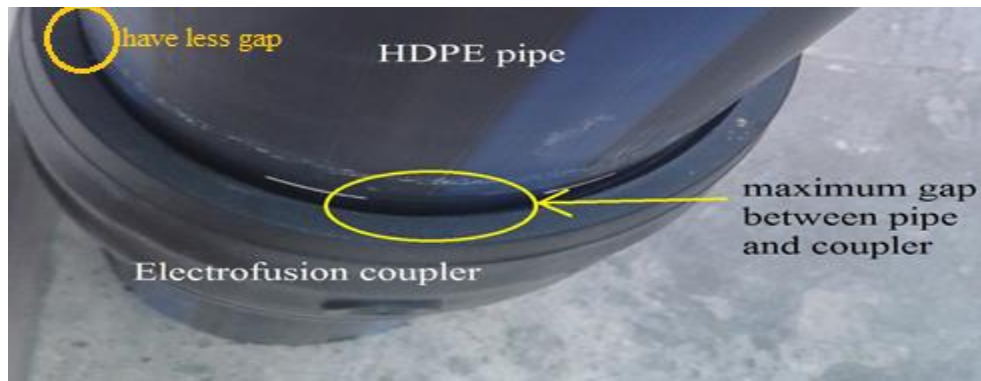
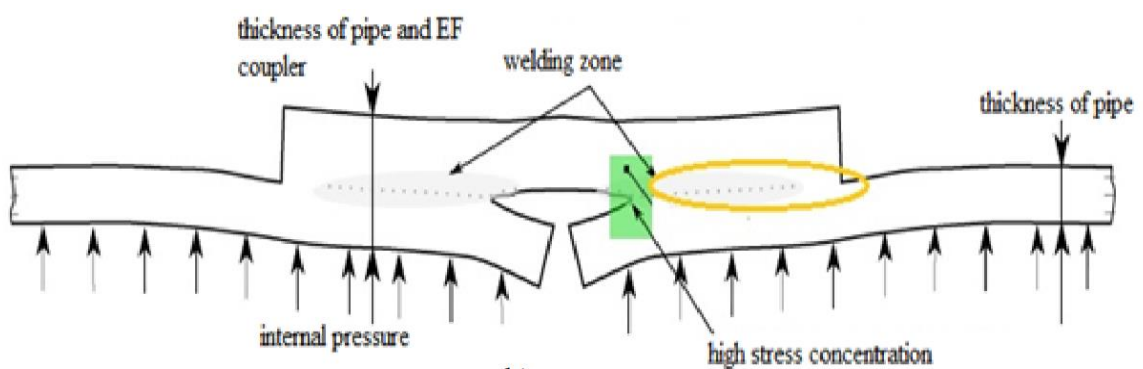


Figure 7.44. The graph between the pressure and time to the EFW sample of hydrostatics pressure of both sample result and it is average without used re roundness and alignment to samples.



a)



b)

Figure 7.45. a) Failure zone after hydrostatic pressure testing of EFW without using performance of re roundness and alignment and b) stress concentration zone and location of start failure [11].

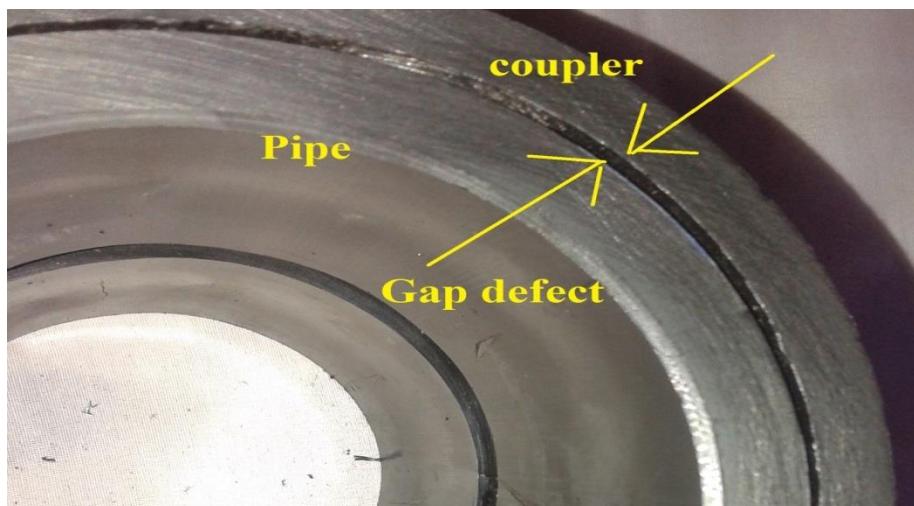


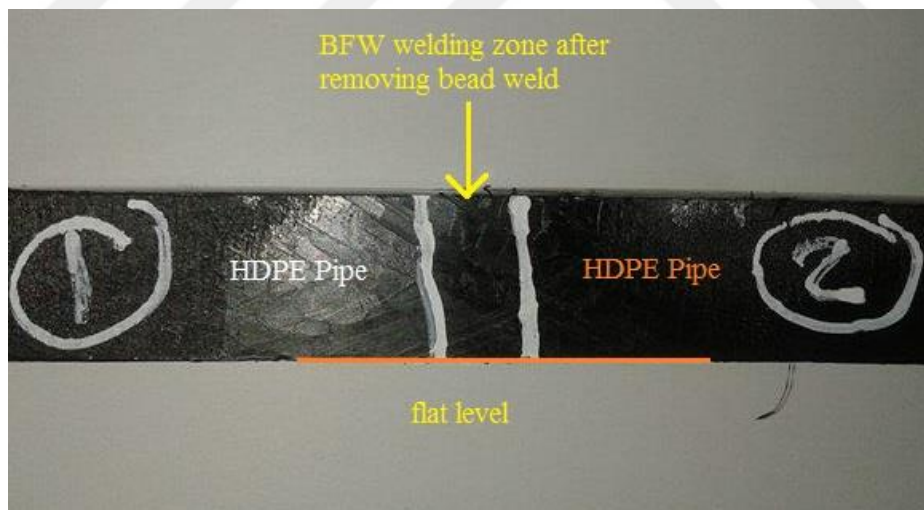
Figure 7.46. Failure place (gap defect) to hydrostatic pressure testing of EFW without using performance of re roundness and alignment.



a)



b)



c)

Figure 7.47. BFW zone which was used alignment and re roundness after testing failure not occurred a) Bead weld and b) sample after testing and c) flat level BFW weld zone.

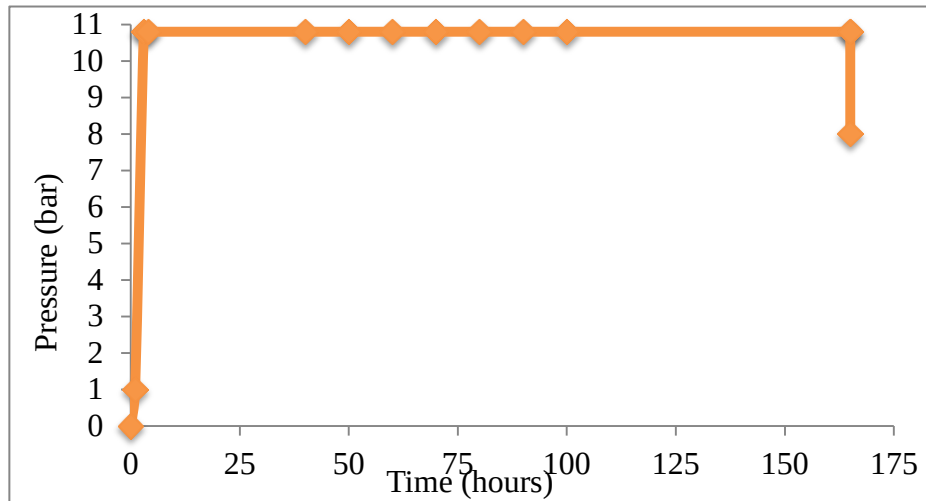
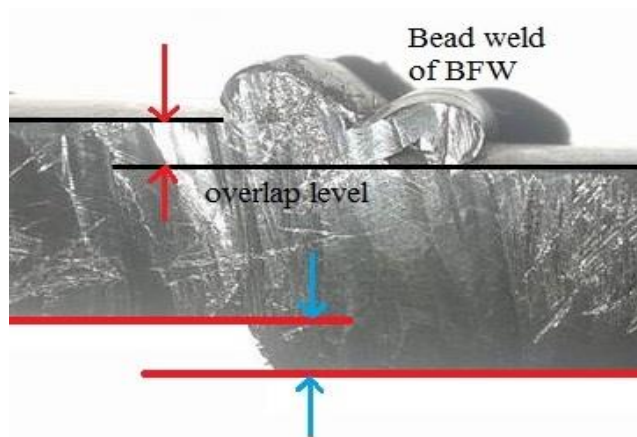


Figure 7.48. The graph relation between the pressure and time to the BFW and EFW sample of hydrostatics pressure of both sample result and it is average with used re roundness and alignment to samples.



a)



b)

Figure 7.49. Pictures of pressure test result of BFW without used alignment and re roundness a) defect of bead in BFW and b) failure place in bead weld of BFW and causes of failure.

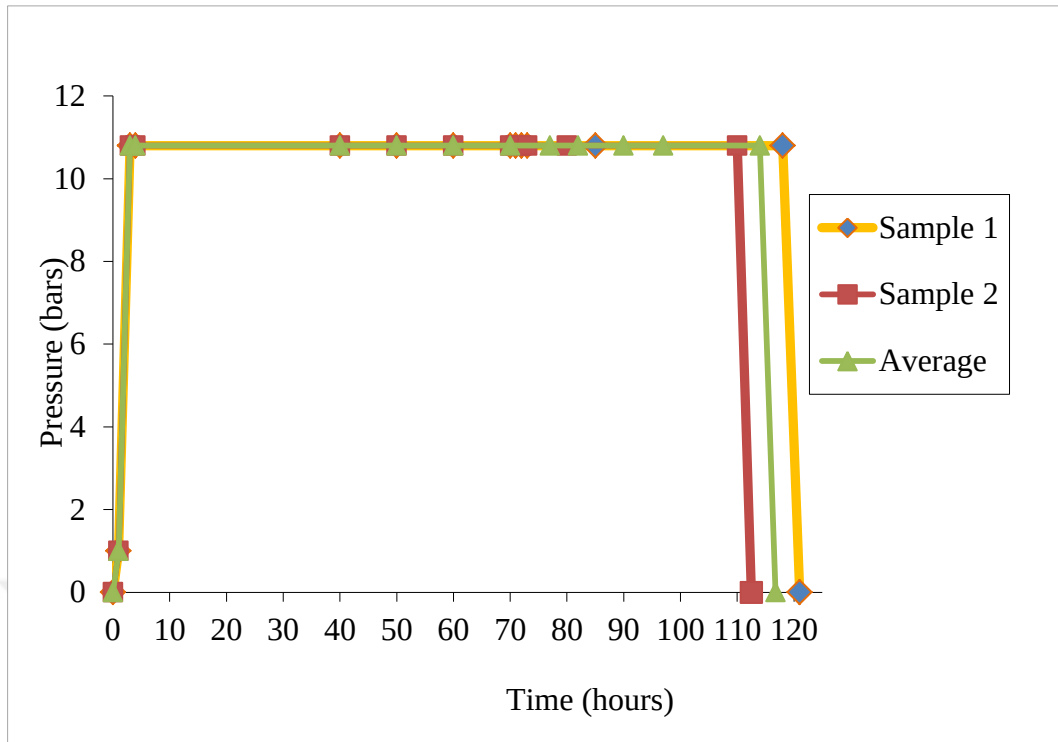


Figure 7.50. Relation between the pressure and time to the BFW sample of hydrostatics pressure of both sample result and it is average without used re roundness and alignment to samples.

Table 7.5. Result of hydrostatics pressure at (hours) in internal pressure 10.8 bar and failure place to the welded (without used re roundness and alignment to samples) and unwelded pipes.

Sample No	BFW without re roundness and alignment (h)	EFW without re roundness and alignment(h)	Un welded and perfect welded (BFW&EFW) (h)
sample 1	121	79	165
sample 2	112.5	72	165
average	116.75	75.5	165
place of failure	in welding zone	in welding zone between coupler and pipe	no failure

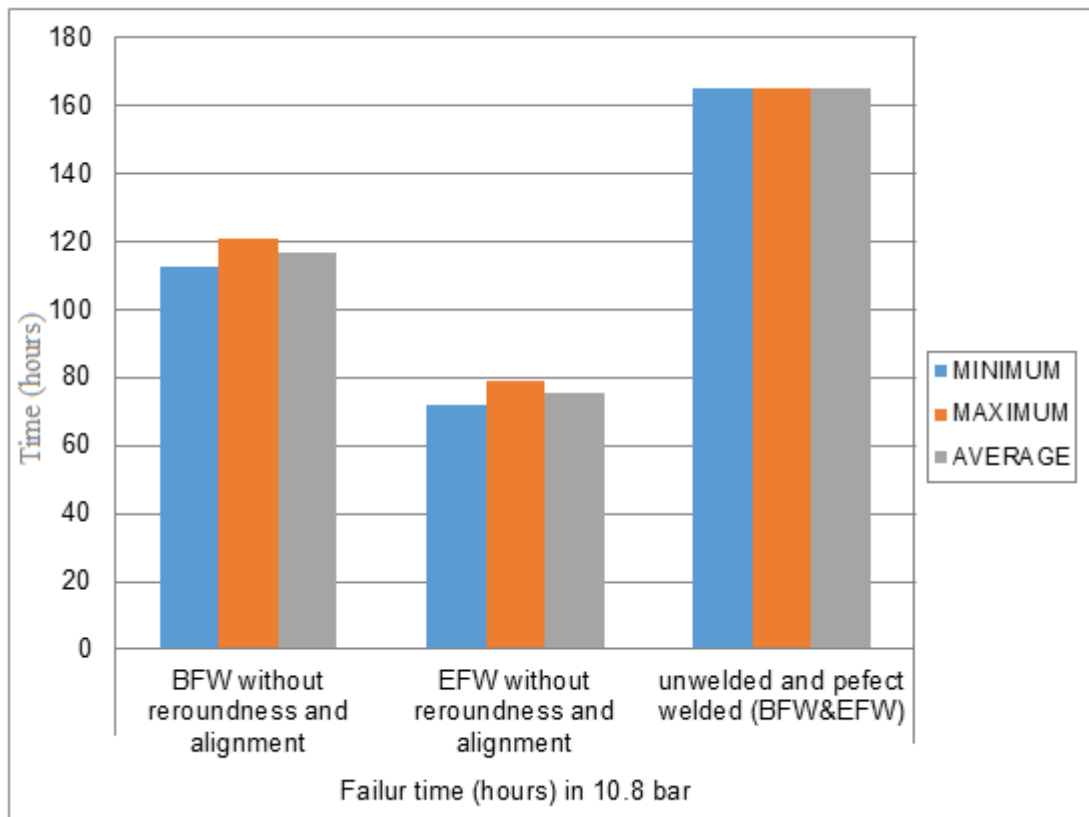


Figure 7.51. Comparing results of hydrostatics pressure at time to the BFW, EFW and unwelded sample of hydrostatics pressure of both sample result and it is average without used re roundness and alignment to samples.

This part of thesis demonstrates how the misalignment and damage to the pipe because of the transportation, incorrect storage and errors in manufacturing can directly affect the performance of the pipe under pressure. This study also shows the importance of the correct use of the re-roundness and alignment tools for the EFW.

During the welding process a normal BFW machine has alignment clamps but because of inadequate more times or because a welder may not have enough experience or is not certified in this field these may not be correct positioned.

These problems can reduce the life span of the joints. Failure in the BFW joints appeared after 116.75 hours and for EFW appearing at 75.5 hours as in Figure 7.51.

8. CONCLUSION

In this study, tensile tests were established of un welded, BFW and EFW samples then results were obtained shows the relationship between the force and elongation with stress and strain which show the maximum force, elastic force and elongation at the failure for each test using the *ANSYS* program for numerical analysis.

Then the tensile strip test of un welded, BFW and EFW *PE100RC* grade pipe were performed. Cracks were created and tensile tests were performed on the welded and un welded samples. Force and displacement graphs were obtained for different welding techniques. The maximum elastic loads and additional elongations at the fracture point were determined.

Finally, the hydrostatic pressure tests were done on the un welded, welded (perfect joint) and other joint BFW (having out of round defects and without the use of re-roundness tool) and EFW (having out of round defects and without use of alignment clamps). A graph relation between the pressure and time was obtained. From these experiments and graphs, the following conclusions may be deduced:

8.1. Tensile Test Results

According to the result for BFW and EFW pipe, it can be said that the variations of the maximum load of tensile standard test BFW samples reduced 4% when it is compared with the sample for the un welded. The failure zone of it is in the un-welded area. For EFW is 10.5% and failure zone in the EF coupler. The elastic force change for BFW is -6% and for EFW is 9% but the elongation difference at fracture for BFW is -86% and for EFW is -1250% according to the un welded pipe as shown in Figure 8.1 and Table 8.1.

8.2. Tensile Test of Strip

8.2.1. Uncracked Samples

The variations of the average elastic load of tensile strips for un cracked BFW and EFW samples according to the un-welded and un cracked pipe samples for BFW is -2.4 % due to the failure zone which is in the butt welded area and for EFW is 24%. The elastic force for BFW un cracked samples is -2% and for EFW is 10%. So, it can be said that the

cracked welding zone of BFW sample has less strength and the EFW pipe is bigger than the un-welded cracked polyethylene material, elongation at the fracture for the BFW un cracked samples are -219% but for EFW is -541%. The ability of elongation for the BFW is higher than that of EFW one by approximately 200% according to the un welded pipes as shown in Figure 8.2 and Table 8.2.

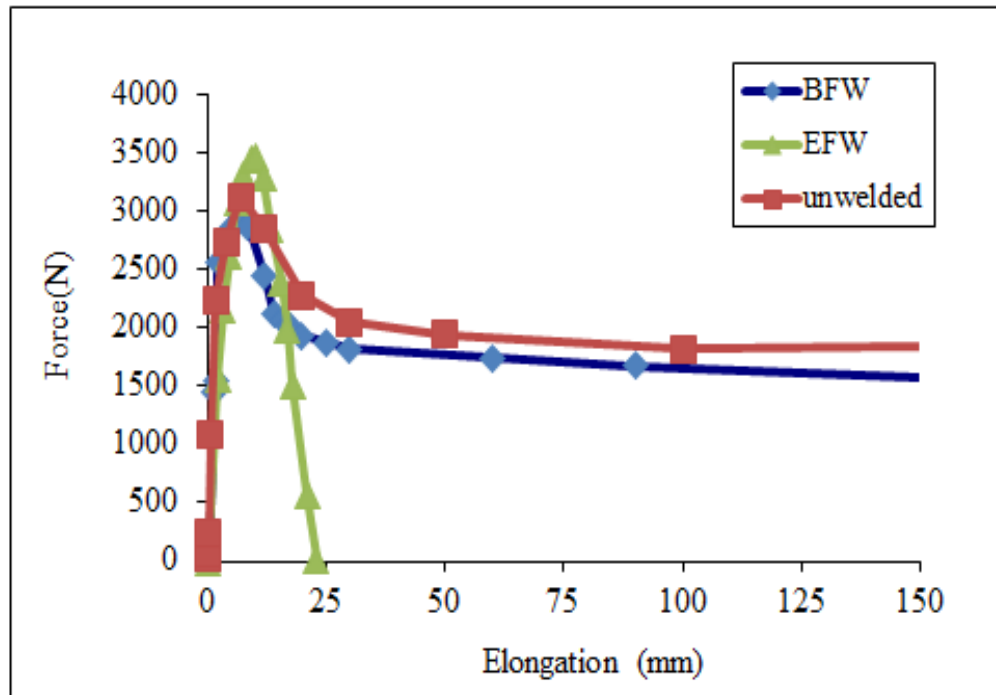


Figure 8.1. Comparison of the force and elongation for un welded, BFW and EFW.

Table 8.1. Failure zones and variation of maximum load, elastic load and elongation at fracture of BFW and EFW samples in tensile test samples.

Welding technique	BFW	EFW
Failure zone	in un welded area	in coupler area
Variation of max. load according to un welded samples	-4%	10.5%
Variation of elastic load according to un welded samples	-6%	9%
Variation of elongation to fracture according to un welded samples	-86%	-1250%

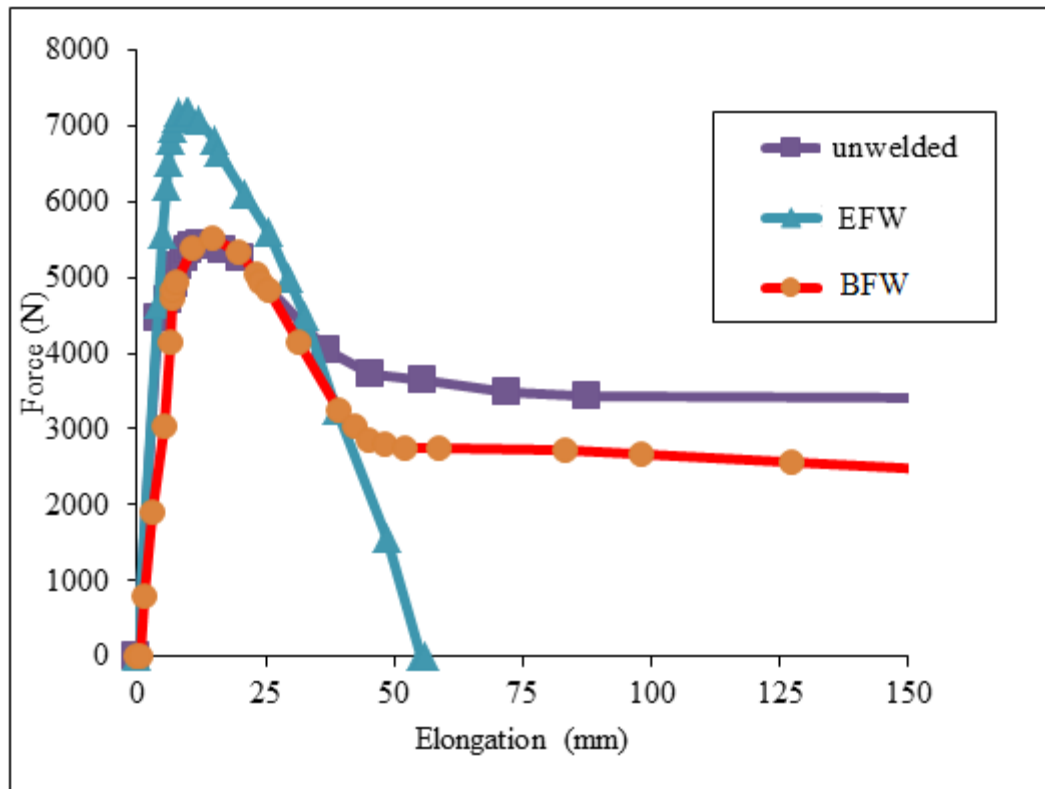


Figure 8.2. Comparison of the force and elongation for uncracked un welded, BFW and EFW average data of results.

8.2.2. Cracked Samples

The variations of the average load of tensile strips for cracked BFW and EFW samples according to the un-welded and cracked pipe samples for BFW is -7.9 % due to the failure zone located in the BF welded area and for EFW is -12.6%. The elastic force for BFW cracked samples are -1.5% and for EFW is 40% the BFW cracked welding zone has less strength and the EFW coupler is bigger than the un-welded cracked polyethylene material. Elongation at the fracture for BFW cracked samples are -5.7% but for EFW is -3.9% This shows the elongation for the BFW and EFW is too near to the un welded cracked pipes as shown in Figure 8.3 and Table 8.2.

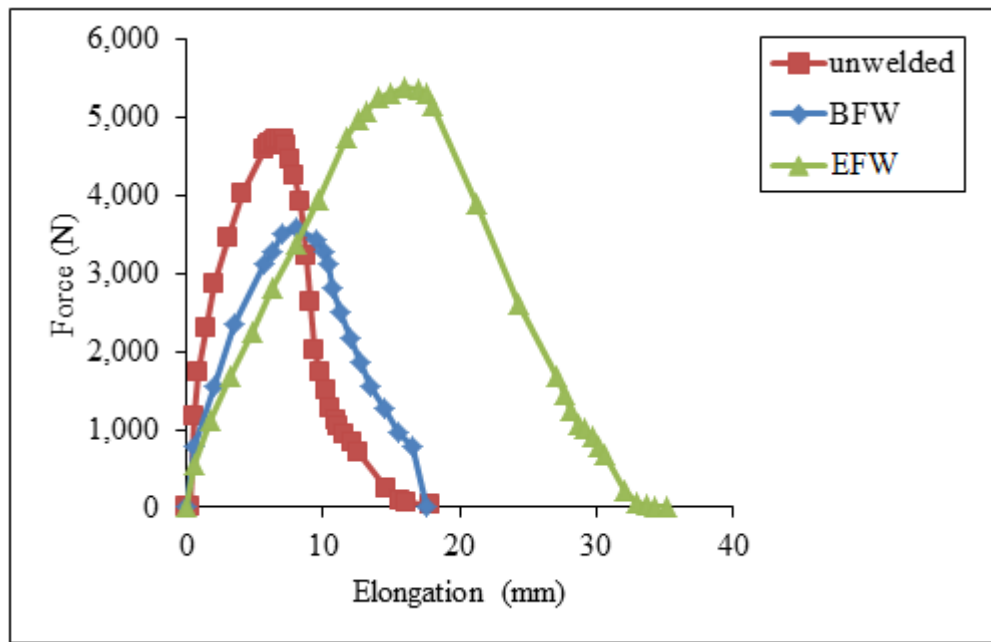


Figure 8.3. Compare relation between force and elongation for cracked strip samples for unwelded, BFW and EFW average data of results.

Table 8.2. Failure zones and variation of maximum load, elastic load and elongation at fracture of BFW and EFW samples in tensile strip.

Welding technique	BFW	EFW	BFW	EFW
Sample	Uncracked	Uncracked	Cracked	Cracked
Failure zone	in un welded area	in coupler area	in welded area	in coupler area
Variation of max. load according to un welded samples	-2.4%	24%	-7.9%	-12.6%
Variation of elastic load according to un welded samples	-2%	10%	-1.5%	40%
Variation of elongation to fracture according to un welded samples	-219%	541%	-5.7%	-3.9%

8.3. Hydrostatic Test

According to the obtained results for welded joints which have the defect of being out of round and the alignment of BFW and EFW samples, it can be said that the variations of the maximum time to failure cause by this can be obtained according to the unwelded and perfect joints in the pipe samples in Table 8.3. For the BFW is -26.6 % and the failure zone of it is in the welded area. For the EFW is -52.1% and failure zone is in the melting zone between the EF coupler and the pipes. Because of the gap defects between the EF coupler and pipe, unbalanced heat distribution between the coupler and pipe occurs.

Table 8.3. Failure zones and variations of time to failure of BFW and EFW samples according to the un welded and perfect joint.

	BFW have ovality and overlap defect	EFW have ovality and without using alignment clamps
Variation of time (h) to failure according to the un welded and perfect joint	-26.6%	-52.1%
Place of failure	in welding zone	in welding zone between coupler and pipe

In this study the following items are deduced :

- In tensile tests according to the maximum average load and the elastic average load in EFW bigger than the BFW and un welded pipe the elongation at the fractures in BFW and un welded samples larger than EFW because of the cracks near the metal wire in EFW which causes starting failures in places between the coupler and pipe as in Figure 7.16.
- For un welded, BFW and EFW samples, numerical analysis was performed with using the ANSYS finite element package program. Good results were obtained according to the experimental data. In the BFW, the welding zone is modeled as functionally grade materials. It is obtained that, there is no difference between BFW and un welded because of good welding application technique.
- Cracks significantly decreases the elastic loads and elongation at fractures according to the uncracked pipes.
- BFW and EFW are important welding techniques. It can be seen that the mechanical reactions for cracked and uncracked strips are approximately like un welded pipes. It can be said that the results of EFW is a little more effective, if the results of BFW are compared according to the un welded pipes.
- The important point for the tensile test results is that the minimum elongation at the fracture is obtained for EFW uncracked pipes. BFW results are bigger than EFW. This point is important for the welding zones since according to Table 8.1 and 8.2, failures of BFW pipes occur in un welded zone due to correct welding that acts like un welded pipe material. But EFW failures are obtained in the coupler area where material

properties are different from HDPE pipe due to material properties changes near to the welding zone (along the metal wire lines) and there is a natural crack in EFW technique. So, stress concentration acts in this area.

- Obtained cracked pipe results can be referenced by any engineer working in this field. Because HDPE pipes are employed in soft soil or sand or any clean soil, anything buried which can cause damage of the pipe will reduce the life span of the pipe networking underground.
- For short a term hydrostatic pressure test appear the resistance in BFW for defects of roundness and alignment is better than the EFW in same condition because of the metal wire in the melting zone which must be run out or moved during the welding process. The BFW machine uses pressure during welding process but in the EFW process does not use pressure and only depends on heated wire. This condition during the cooling time is when the defect will appear as in Figure 8.4. For BFW in this condition a defect will cause reduction in thickness of the joint.
- BFW are more economic compared with the EFW. EFW method needs a coupler for welding, but BFW does not need a coupler this situation causes the higher cost in EFW method. For this reason and obtained results which are approximately same for perfect joint condition, the BFW technique is preferred to new engineering service projects. But the EFW method is suitable in repairs and maintenance of water and natural gas network pipe because of the portability of the welding machine and can be used for repairing specific area of the pipe network as shown in Figure 8.5.



Figure 8.4. Alignment defects in EF welding.

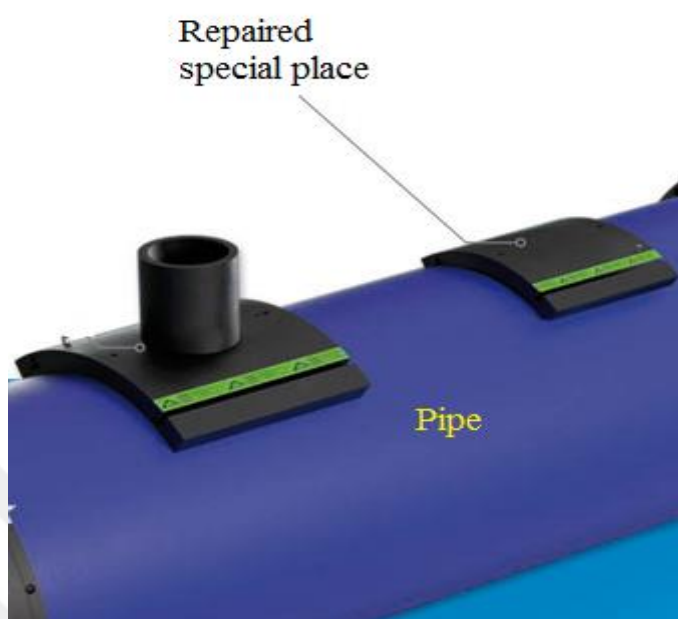


Figure 8.5. Repaired special place on pipe by EF fitting.

9. RECOMENDATIONS

According to the results of this study, the following recommendations are noted:

- A full range of mechanical properties should be presented, for example bending, fatigue, hardness and impact tests can be done for joining of PE pipes.
- Non destructive testing such as ultrasonic, X ray and phased array for finding the types and shapes of defects in the joining of PE pipes can be used.
- It can be identified the differences of failure modes between BFW- EFW joints by performing long term pressure test.

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Graduated from technical engineering college in Sulaimany polytechnic university 2008/ B. Sc. Degree, sulaimanyah region in Iraq. B.Sc. in Mechanical engineering and main subject includes designing of mechanics, material ,manufacturing process ,strength of material, Fluid mechanics(water network distribution),welding application, welding inspection, welding technology, thermo dynamics, heat transfer, design of steel structures, (design & inspection) of pipe welding & plate welding, Welding Technology, welding Application, welding procedure specification WPS, computer numerical control

- I have 7 years experience in water working working as:-

I worked one year in sulimanyah governorate as water network project supervisor in grdagozina- kalar.

I was worked 24 month in (maintenance department in Director water suburb of Germaine).

I was worked 4 years in kalar water directorate which includes the departments (water treatment plant – projects - planning - water Quality control , maintenance and repair - accountant-administration) which am working as 1 year as engineering and 3 years as director of kalar district water directorate to 01-01-2015.

With regards.....

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