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GRAPHICAL MODELLING OF A BUTT FUSION WELDING MACHINE FOR THERMOPLASTIC MATERIALS

Abstract: *Welding is the process of merging two or more elements from metallic or thermoplastic materials, throught a heat or pressure source. The joining of the elements is ensured by the welded bead, which is a solidified quantity of material which allows the continuity of the crystalline structure of the material. In this paper, some basics about the welding of plastic materials are presented, as well as a 3D graphics modeling of a butt-welding machine achieved using Autodesk Inventor design environment. At the same time, in the software programme, the heating element modelling is carried out, namely, the electric hob with thermoregulator. This type of welding machine is used in a large number of applications and requires a proper design and dimensioning of the elements for ensuring reliability, strength, design flexibility, and low processing costs.*

Key words*: head-to-head welding, samples, thermoplastic materials, heater element.*

1. INTRODUCTION

Plastics, as presented in figure 1, are synthetic macromolecular products from which, by mechanical or thermal processing, objects of different forms can be obtained, with wide uses in industry and trade.

In the choice of materials for the manufacture of different parts, both the properties of the material and the methods of measuring these properties should be taken into account.

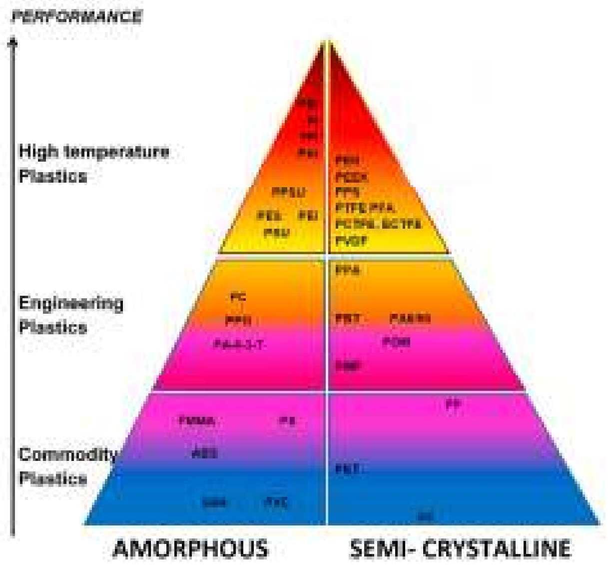


Fig. 1 Plastics pyramid [1].

Since the influence of materials structure, environment and transformation parameters are relevant for the measured properties, the evaluation methods have been normalized, but manufacturers may develop internal rules or rules imposed by customers [2], [3], [4], [5].

A plastic bonding process is welding process which, compared to other joints, such as bonding with adhesives or jointing with mechanical elements, presents a number of advantages: high productivity, high mechanical strength of welded joints, low workload, specific reduced costs, improving working conditions, sensitive shrinking of working surfaces, the possibility of framing the job in an automated or robotic assembly line.

In Table 1, several types of polymer materials are presented, the most commonly used in the industry.

Table 1

Types of polymeric materials

PVC-U	Non-plasticised polymerised vinyl chloride
PVC-C	Chlorinated polymerised vinyl chloride
PVC-HI	Polymerised vinyl chloride with High Impact
PVC-ESD	Vinyl chloride Electro Static Discharge
PP-H	Polypropylene Homopolymer
PP-C	Polypropylene Copolymer
HDPE	High-Density Polyethylene
HMWPE	High Molecular Weight Polyethylene
UHMWPE	Ultra-High Molecular Weight Polyethylene
PC	Polycarbonate
PA 6	Polyamide (Nylon)
PA 6.6	Nylon 6,6 Polyhexane diyladipamide
PET	Polyethylene Terephthalate
PVDF	Polyvinylidene Fluoride
PSU	Polysulfon
PPSU	Polyphenylsulfone
PEEK	Polyetheretherketone

The processing of thermoplastic polymers, respectively their behaviour during welding, is based on reciprocal relationships between process parameters (temperature, temperature actuation time, pressure, pressure actuation time etc.) and the structure of polymers, which is strictly determined by the molecular connection mechanisms [6].

Welding of thermoplastic polymers can only be achieved in the area of temperature between softening, namely the melting of crystals, and the temperature of thermal degradation. During the welding process, activated molecules (Brownian moving) are linked on the basis of freely favoured valences of flow movements in the viscous field, determined by the welding pressure.

2. BUTT FUSION WELDING OF PLASTICS

The butt fusion welding (polyfusion) is the processes that uses a heating element between the parts that need to be joined.

This will heat the surfaces of the end parts up to the melting temperature, is removed from the joining area and, under the action of the pressure, the pieces are presses together.

In general, a profusion welding equipment consists of: frame with support, pressure and welding system, pipe clamping system, heater element actuation system and the command and control panel, which allows to set and monitor the entire welding process. An example of polyfusion welding equipment is shown in figure 2 [7].

Fig. 2 Polyfusion welding equipment [6].

The main technological aspects that should be checked and achieved before performing the butt fusion welding of plastics are the following:

- precise selection of clamping system and centring of the pipe heads (movement of the edges of the tubes must not exceed *10 %* of the thickness of the tubes' walls);
- ovality and alignment of the ends of pipes;
- the smoothness of pre-processing of tubes ends;
- removal of the oxide layer;

There are three welding procedures for butt welding PE: single pressure – low fusion jointing, dual pressure – low fusion jointing, and single pressure – high fusion jointing. The main butt fusion welding process are [8]:

- *heating element temperature*;
- *drag pressure*, required to overcome the sliding frictional drag force of the machine and pipe;
- *bead-up pressure*, applied on the heater device by the pipe end during the bead-up phase of the jointing cycle;
- *heat soak pressure* and *time*, that maintain the pipe in contact with the heater device;
- *fusion jointing pressure,* applied on the pipe ends during welding;
- *fusion jointing time*, period allotted for bead roll-over before cooling-cycle reduced pressure.
- *cooling time*, with pressure, when the joint remains under pressure when still clamped and without pressure, after the cooling time under pressure.

In normal conditions, the natural cooling of the weld bead is applied. The pipes can be welded in the absence of atmospheric currents and at a temperature higher than *0 °C*.

At temperatures below *0 °C*, it is necessary to use insulated mobile booths, and in rainy time, mobile tents. For the pipes welding, as can be seen in figure 3, electric heating devices, which can be of two types, are used: with discs and rings.

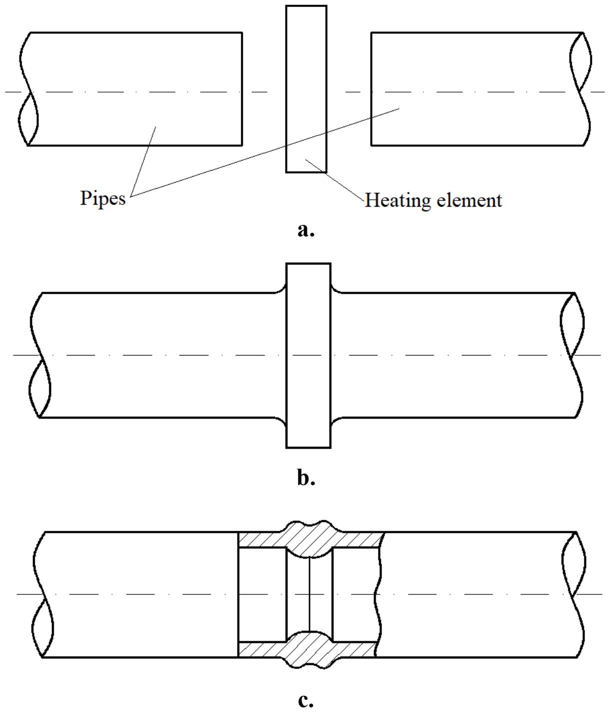


Fig. 3 Welding plastic tubes:
a-preparation; b-heating; c-final merge.

There are special devices to support the melted heads of pipes. Cut and profiled in advance, the pipe samples of the same diameter are fixed in the clamping system. The ends of the tubes are brought in contact with the heated element (a ring), using a mobile platform. The amperage is between *80-200 A* and the voltage of *3-6 V*. The ring, warming up to the temperature of *180-200°C*, melts the ends to the surface pipes. The heated ring is removed, and the melted ends of the pipes are pressed of approximately $1\text{-}2\ kgf/cm^2$. For example, in the cooling phase of polyethylene, a sturdy weld bead is formed. The productivity of the machine reaches up to five joints per hour at a pipe diameter of *300 mm*. A similar machine consists of handgrip devices, movable and fixed, with free removal of a semi-clamp.

For welding of plastic pipes with a diameter of *60-240 mm* and *100-240 mm*, universal installations are used. The mounting devices of the installations, which clamps the pipes, move simultaneously using a lever mechanism. For melting the ends of the pipes, the electrical heating device with disc is applied.

The heating temperature of the working surfaces of the disc should be controlled using contact thermocouples. For on-site welding of polyethylene pipes with diameters of *50, 100, 125, 150* and *200 mm*, installed in segments of *6, 8* and *10 m* in length, a mobile installation should be used, for the butt fusion welding process. The heating temperature of the device can be adjusted using a thermoregulator and should not exceed *210 °C*.

For vertical welding of pipes with a diameter of *150, 200* and *300 mm* of high-density polyethylene, a special installation is used. As a heating device, a double electric disk with thermoregulator is used, as shown in figure 4.

Fig. 4 Electrical disk with thermoregulator [8].

The electrical disk is mounted on the installation body and is connected to a spring piston. The angle of rotation of the disk is equal to *135°*. The welded joint of the pipes is quite durable with a diameter of *200* and *300 mm* to a depth exceeding *400 m*.

3. THERMOPLASTIC MATERIAL FUSION BUTT WELDING MACHINE GRAPHICAL MODELING

In the figure 5 is presented the 3D model of the thermoplastic material butt fusion welding machine, performed practically for experiments, using 3D modelling software *Autodesk Inventor*. The samples are pipes with diameters of *35 mm* and lengths between *100* and *250 mm*.

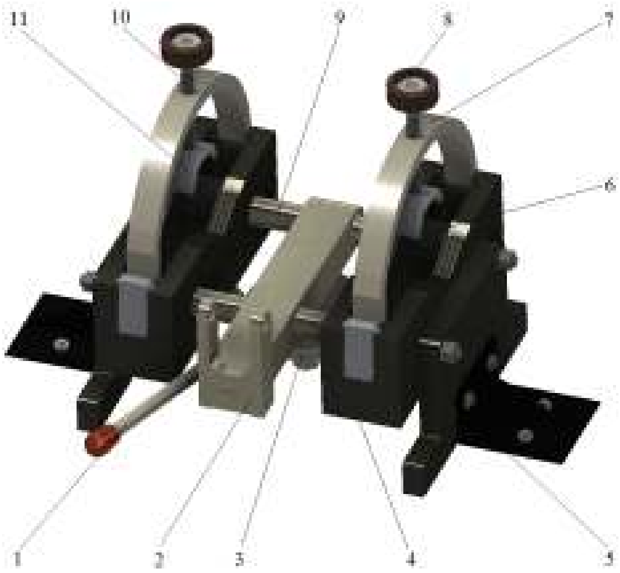


Fig. 5 Thermoplastic materials butt fusion welding machine - 3D model: *1* - lever mechanism with knob; *2* - heater element support; *3* - samples positioning mechanism; *4* - sample support; *5* – supporting element; *6* - muff coupling; *7* - clamping element; *8* – clamping positioning wheel; *9* - shaft; *10* - screw; *11* - samples fastening element.

Each component within the butt fusion welding machine was performed in the *Autodesk Inventor Part* (**.ipt*), module, due to the complexity of its design [9], [10], [11]. The final model of the device was obtained in the *Autodesk Inventor Assembly (*.iam),* in which the constraints actually used to assemble all components from a sub-assembly or the whole, being: surface constraints-*Mate* and *Flush*, which it helps create the contact between two surfaces, one from the other, distance-offset constraint - *Offset Constraint*, constraints for setting the angles between two surfaces - *Angle Constraint*, constraints of fastening the main element to the other components - *Grounded* etc.

In the paper, only a series of modelled elements belonging to the device are presented, the other components being made in a similar way and using approximately the same defining commands.

Modelling of the heater element support

In the *Sketch* module, from the *XY* projection plane, a sketch is designed to generate the dimensions of the heater element, using the *Rectangle* command, with a width of *35 mm* and a height of *30 mm*. The *Extrude* command is used in the 3D module to design the solid, with a length of approximately *208 mm*.

The design of the other component elements of the support is carried out both with the *Extrude* command and other 3D drawing and editing commands, such as *Hole*, *Mirror* and *Fillet*, thus obtaining the final model, Figure 6. After the modelling of the heater element, the support of the samples subjected to the welding process are modelled.

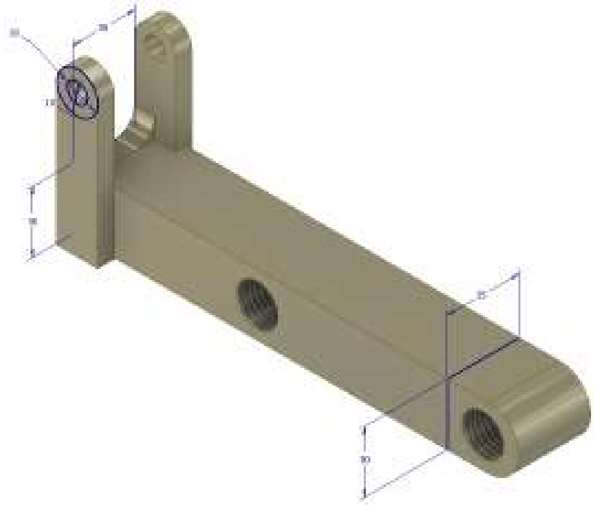


Fig. 6 Heater element holder.

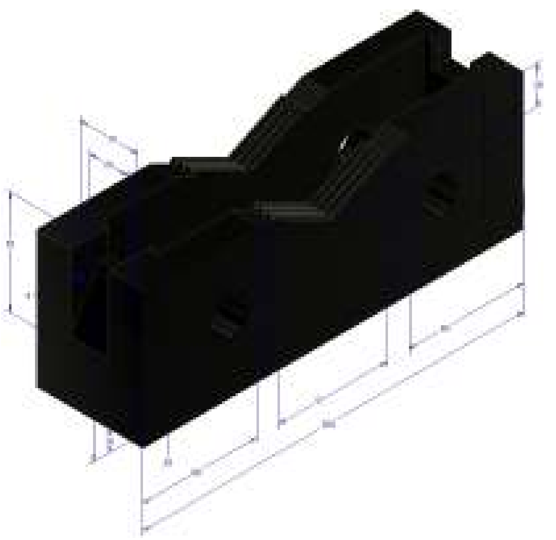


Fig. 7 Support test tube.

Modelling of the samples support

In order to obtain the support of the test tubes, as shown in figure 7, the *2D - Line*, *Rectangle*, *Circle*, and *3D - Extrude*, *Hole*, and *Mirror* drawing commands were used. In order to obtain the hole in which the closing element *7* from figure 5 is positioned, draw a straight, at a distance of *55 mm* from the *YZ* plane, in which the support bracket was designed.

With the *Angle to Plane around Edge* command, an angled plane was generated at an angle of 60^0 from the right and, through the *Extrude* command, the *Cut* module, the final model of the hole is obtained.

Modelling of the lever mechanism with knob

In the *XZ* plane, the sketch of the workpiece will be drawn up using *Line* and *Circle* commands with dimensions according to figure 8. The length of the lever is approximately *160 mm*, diameter *Ø10 mm*, which is obtained using the *Extrude* command. The shape of the knob is obtained using the *Circle* command, which is designed in 3 different planes. The planes on which the 3 circles are drawn shall be obtained using the *Offset from Plane*, which are arranged between them at distances of *5 mm* and *25 mm* respectively. In the *3D* design environment, using the *Loft* command, the profiles merge with the model shown in figure 8.

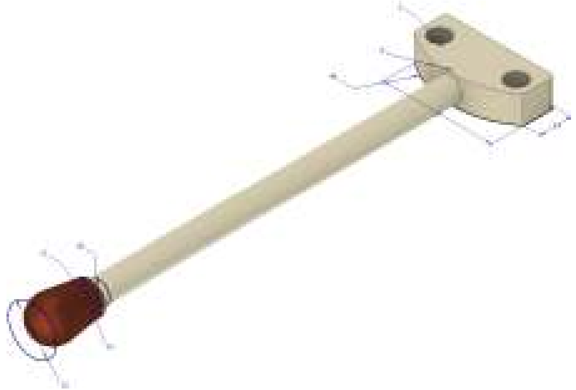


Fig. 8 Lever mechanism with knob.

Modeling of the samples positioning subassembly

The subassembly for the pipe's samples clamping, subjected to welding process is composed of 3 elements, see in figure 5: positioning wheel *8*, clamping bolt *10* and sample fastening element *11*.

In the *Sketch* module, from the *XZ* projection plane, with the help of *Circle, Extrude, Chamfer* and *Fillet* commands, the *3D* wheel model is obtained, with the dimensions corresponding to figure 9. With the *Extrude* command, with a length of *80 mm* and the *Thread* command, the virtual model of the *M10x1* mm left bolt is obtained for the generation of threads.

In order to obtain the virtual model of the sample fastening, the first step is to generate a solid, using the *Rectangle* controls in *2D*, with a length of *45 mm* and width of *22 mm* and the *Extrude* command, from the *3D* environment, with a height of *22 mm*.

On the side of the solid, a sketch is designed using *Line* and *Arc* commands. Thus, through the *Extrude* command, the *Cut* module, the final virtual model of the subassembly for pipe positioning, is obtained (Fig. 9).

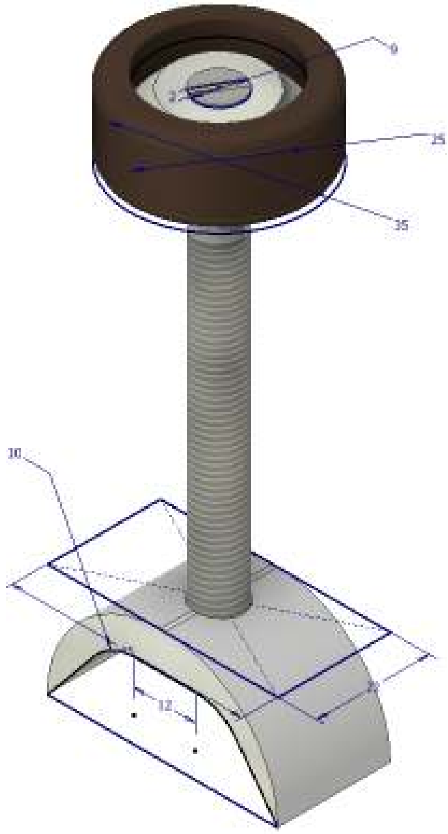


Fig. 9 Subassemblies fastening the samples.

Modeling of the elements for clamping, fastening and positioning

Screws, nuts, muffs couplings, as well as the other elements that forms the fusion butt-welding device, as figure 10 shows, have been obtained using specific graphical modelling commands, namely *2D - Line, Circle, Arc, Polygon*, as well as *3D* commands - *Extrude, Revolve, Hole, Fillet, Chamfer, Thread* and *Mirror*.

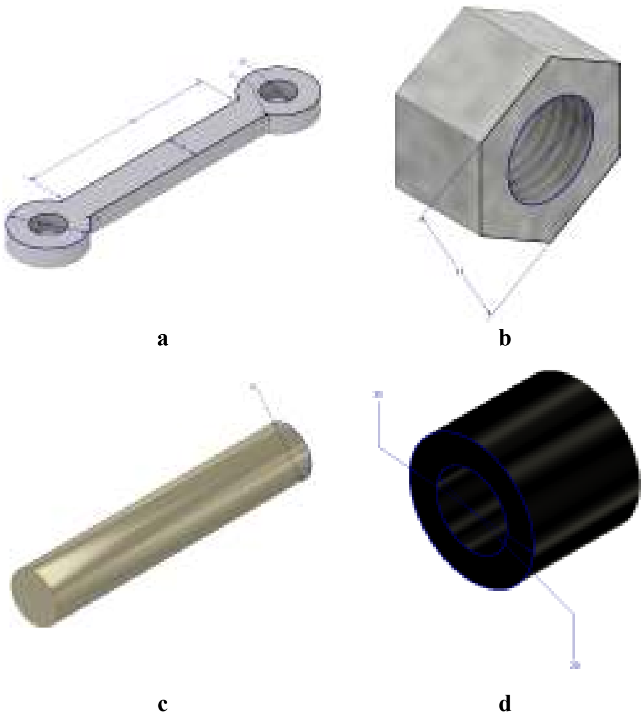
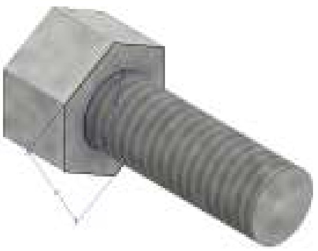


Fig. 10



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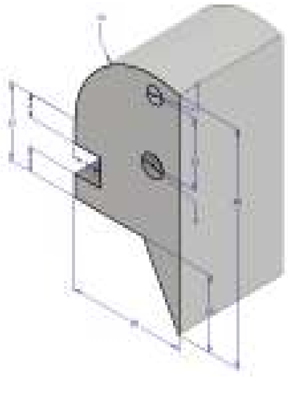

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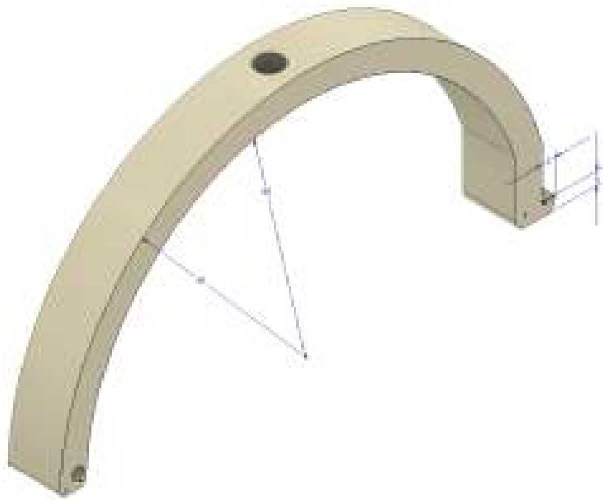

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Fig. 10 (continuing) Clamping, fastening and positioning elements of the thermoplastic materials butt fusion welding machine: *a* - element of fastening the samples; *b* - nut; *c* - rod; *d* – muff coupling; *e* - adjusting screw; *f* - fixture of the sealing element of the sample; *g* - sealing element of the sample.

Modeling of the heater element

The electrical disk heater element is also modelled in the *Autodesk Inventor*, *Part* module (**.ipt*), following its assembly alongside the fusion butt welding device, so that the welding process of the pipes can be observed.

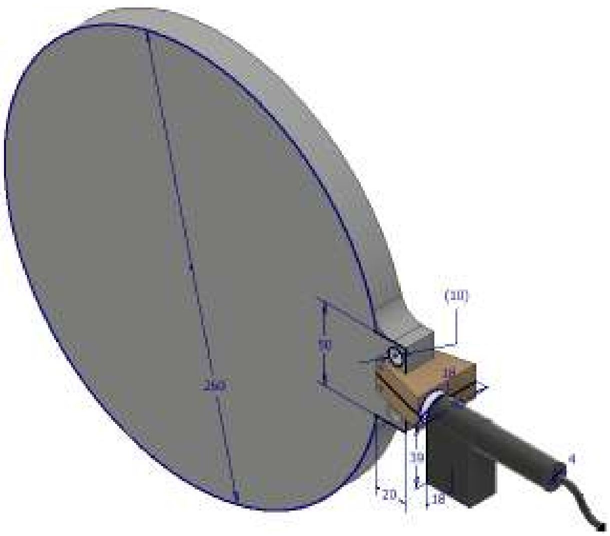

Fig. 11 Electrical disk heater.

In the *XY* plan, the sketch of the workpiece is performed, in which the *Line* and *Circle* commands are used, with dimensions in accordance with Figure 11. The maximum diameter of the heating element is *Ø260 mm* and, using the *Extrude* command, the thickness of *20 mm* is obtained. The handle and other component elements that make up the electrical disk are also obtained using *2D* and *3D* drawing commands such as*: Line, Circle, Extrude, Hole, Mirror, Fillet* and *Sweep*, Figure 11.

Figure 12 shows the assembly between the thermoplastic materials butt fusion welding machine and the electric hob, made in the *Autodesk Inventor Assembly (*. iam)* module, using the *Mate, Flush, Offset Constraint* and *Angle Constraint* constraints.

Fig. 12 Assembling between the thermoplastic materials butt fusion welding machine and the electric hob.

In order to achieve the welding process, samples made from non-plasticised polymerised vinyl chloride *(PVC-U)* are used in experiments, with proprieties according to international standards [12], [13], [14]. Polymerised vinyl chloride is a plastic material, having both a very good chemical resistance and excellent mechanical and thermal properties, as defined in Table 2.

Table 2

Mechanical properties of the Polymerised Vinyl Chloride

Features	Value
Density [g/cm³]	1.38
Tensile Strength [N/mm²]	≥ 52
Modulus of Elasticity [N/mm²]	≥ 2500
Charpy Impact Strength at 23ºC [kJ/m²]	≥ 6
Charpy Impact Strength at 0ºC [kJ/m²]	≥ 3
Thermal Conductivity [W/mK]	0.15
Linear Thermal Expansion [mm/mK]	0.07-0.08
Water Absorption [%]	≤ 0.1

The samples were modelled in *Autodesk Inventor*, *Part* module (**.ipt*), using *Circle* commands with a maximum diameter of *Ø30 mm* and *Extrude*, with a length of *150 mm*.

The *CAD* model of the whole thermoplastic materials butt fusion welding machine is presented in the figure 13.

Fig. 13 The *CAD* model of the thermoplastic materials butt fusion welding machine.

4. CONCLUSIONS

The fusion butt welding of polymer materials using heater elements has a large number of practical applications, requiring mobile, fast and versatile welding machines, consisting in proportionate and easy-to-use elements. For this reason, a proper modelling of the device is needed in order to meet the industrial requirements and on-site installation development.

As an industrial method, a number of technological parameters must be respected from the precise aligning and centring of the pipes heads, adopting proper clamping system, to the rigorous control of the main process parameters such us heating element temperature, drag, bead-up, heat soak and fusion pressure and respecting the time intervals from the melting of the parts, the joining and cooling phases. In order to achieve maximum precision a proper design of the welding installation should be accomplish.

Therefore, the thermoplastic materials butt fusion welding machine has been modelled graphically in the *Autodesk Inventor* software package and has been physically produced from its own materials, based on the principles of operation of industrial, but small-scale applications.

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