The High Frequency Welding Aptitude of Thermoplastic Polymers

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The debates study the influence of the molecular structures for polymers welding and establish the conditions when is possible to obtain a welding joint of these and a transition area near welding with properties which ensure good usage. The testing of aptitude of materials for high frequency (HF) welding, were done with Polyvinyl Chloride (PVC) foils with textile insertion and Malivat materials, defining in an experimental way, the optimum process parameters which ensure a good resistance breaking for welding.

Key words: polymer, structure, welding ability

The usage of plastic materials in industry suffered an important increase in the last 50 years, and development of new welding technologies of these materials was the main focus. This development is an effect of these new components asked in design phase in the innovative fields as medical, automotive and packaging industry [2, 5]. In this direction, the welding of thermoplastic materials with HF proceed is a field with a big interest in production and manufacture.

From this reason, we will study in this debate the high frequency (HF) welding aptitude of thermoplastic polymers used in automotive industry [9, 10]. The automotive manufacturing records the highest increase of usage of plastic materials: in average, worldwide with 44% per year. The main types of polymers used are Polyvinyl Chloride (PVC), polyolefin and styrene. The usage of plastic materials in automotive industry is in a continuous diversification and increase.

The dependency of welding ability based on molecular structure

The study regarding the possibility of joining the polymers through welding in alternative electrical field with high frequency, considering only their dielectric behaviour not sufficient. For this analyze it is important to know the ability of material for welding, this technological property depending mainly on molecular structure (fig.1) [3, 5].

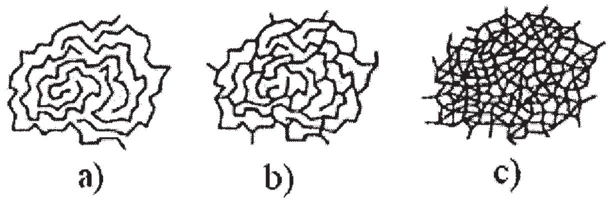

Fig. 1 Molecular structure of polymers: a – thermoplastics; b – elastic; c – plastics

For example, the phenol resins, even if can be heated up in HF field, have not the properties to be joint through HF welding, because they are durcoplastic materials, which have not the steeping vat domain and flow domain (fig. 1c). There are some thermoplastic materials for which the melting capacity from one to the other (molecular combination) is missing. Plexiglas for example is a material where the succession of thermically conditioned states specific to the thermoplastics is not respected [9, 10]:

1.Inelastic domain;	4. Flow domain;
2. “Frost” domain;	5. Thermoplastic domain;
3.Thermoplastic domain;	6. Disintegration domain.

Another example is polytetrafluorinetilene, which belongs to thermoplastics from structure point of view; this material should be welded with special precaution. The same behaviour has also the polyurethane, which have

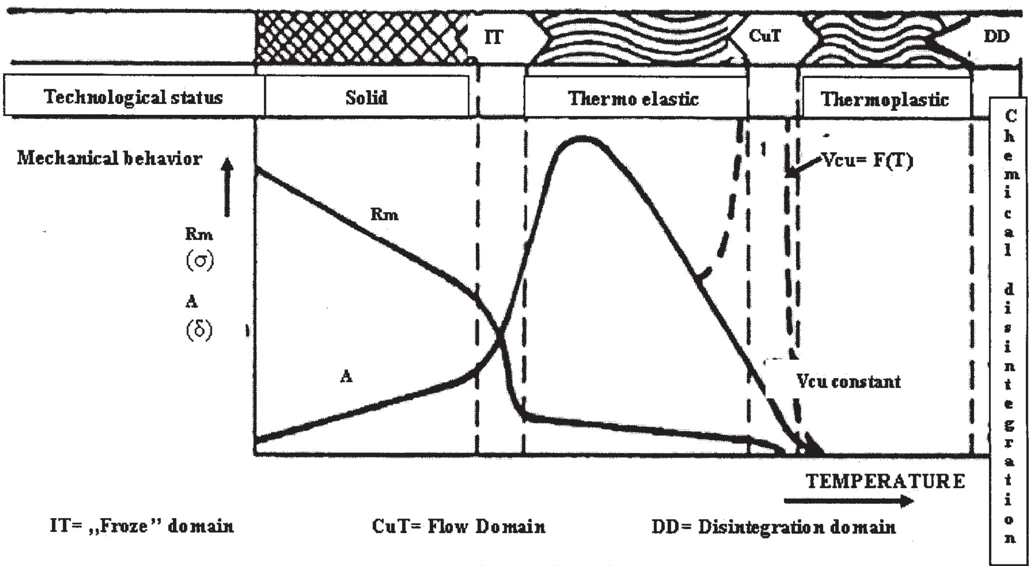

Fig. 2a. Representation of status form for amorphous polymers
Rm (σ) = Breaking resistance, A (δ) = Elongation

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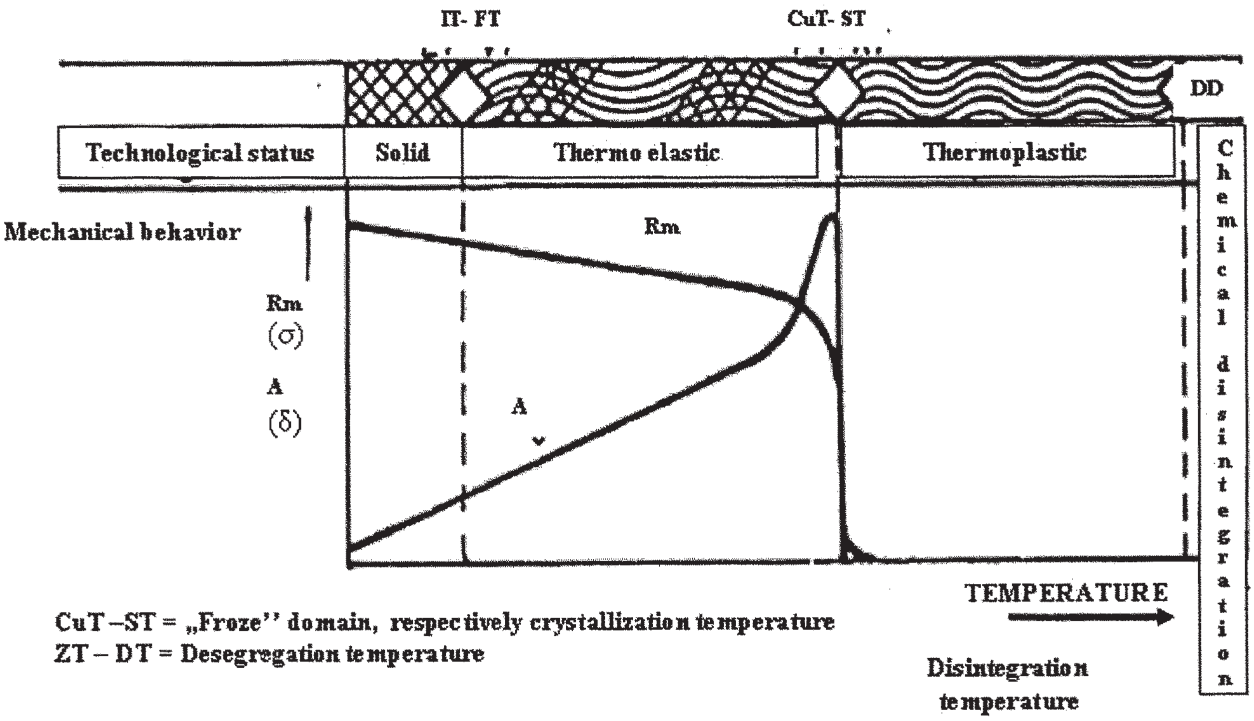

Fig. 2b. Representation of status forms for partial crystalline polymers

a smaller ability for welding with increase of molecular chain [2, 3]. So, the aptitude for welding supposes to have a straight linear thermoplastic material which has the melting temperature field and also a flow temperature field (fig.2).

If for thermoplastics with amorphous structure appear three clear status domains with two thin transition domains, for partial crystalline polymers the thermoplastic domain is almost suppressed. Besides this, for partial crystalline structure materials, because of morphologic stucture, the transition domains are limitated at few degrees, so that we can say that it is a transformation point. This behavior has a desadvantage for HF welding. It's main challanging to weld the thermoplastics, where flow and desegragation domains are in direct or reverse succession.

For almost all materials, like polyamide, appears a sudden transition from thermo elastic to the thermoplastic domain [9, 10, 11], so that this state is considered almost a domain and we can describe this as a flow point. In this condition the thermoplastic have very low viscosity (almost liquid) and for this it is affected the joint welding and the transition areas. A biggest domain of melted bath, where the materials looks like ,,honey'', has an advantage because appear a step by step transition to thermoplastic domain. For Polyvinyl Chloride (PVC) foils this premise in achieved.

The specialists committee has not a cammon point of view regarding an effective flow domain of PVC existence, decisive is the molecular melt capacity under heat action. Even if for this polymer is possible to obtain a joint welding under pressure action, due to variety of forms supplied, appears a different rheological behaviour during process. For these reasons, to appreciate the welding ability of polymers, it has to be considering the viscosity of melt and the dielectric behavior of polymers.

Experimental part

Introducing a dielectric material into an electric field, a part of energy goes into the substance and in almost all the cases it is transformed in to heat.

The energy dissipated into the material, under the influence of electrical field, represents the dissipations in dielectric (the material to be welded).

The thermoplastic materials which present a good ability for HF welding are [3,6]:
- Polyvinyl Chloride (PVC)- soft and hard;
- Polyamide (PA);
- Polyester (PES);
- Thermoplastic Polyurethane (TPU);
- Few types of composite materials (TPO).

A HF welding tool can use maximum 2 layers of materials with thickness between 0,2- 5mm.

The materials can be welded without constrains from equipment point of view if we design this for maximum 20cm ^{2}/ kW [3].

The HF welding machine (fig. 3) [6] contains an induction coin, which is supplied with radio- frequency electrical power, which generates a high frequency electro-magnetic field, which acts likes an electrical capacitor (welding tool like armatures and the material which have to be welded as dielectric).

In the ferromagnetic components and also for plastic materials with ceramic particles insertion, the heating up is obtained by hysteresis (fig.4), as magnetic component of electromagnetic field which repetitively interact in the crystalline structure of ferromagnetic material.

The Ferro- electricity is the physical property of materials at the spontaneous electrical polarization exposure, that makes possible to change each bipolar direction through application of external electrical field.

The experiment evidence for this oscillatory field is the hysteresis loop (fig.4).

Due to spontaneous polarization it results a change of contact surface, which can cause a power flow for ferroelectric capacitor (welding tool), even without an external voltage applied to the capacitor. The two influences which will change the dimensional frame are the force and the temperature [3].

As a testing method to establish the welding aptitude for HF welding of different dimension of PVC foils, it was considered PEUGEOT S.A. test method D41 1033, which

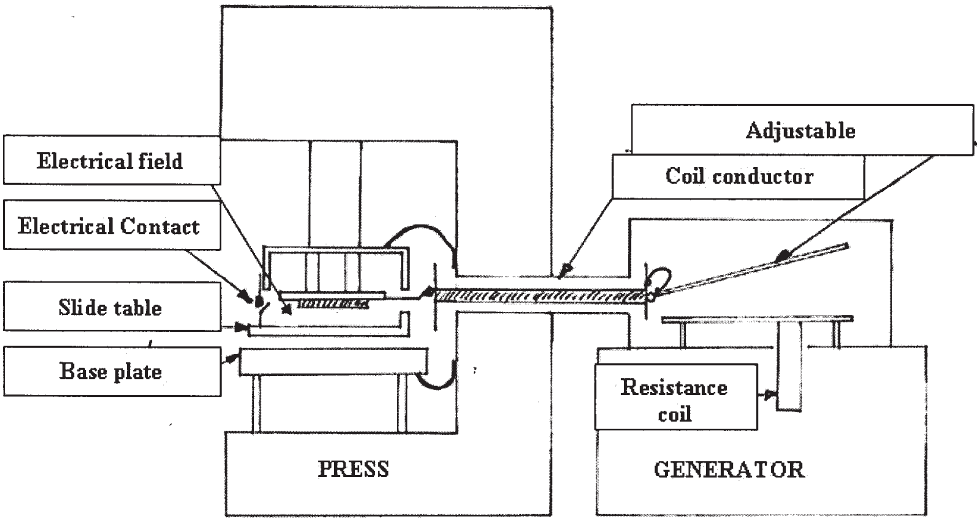

Fig. 3. Electrical and hydraulic map of HF welding machine used in experiment

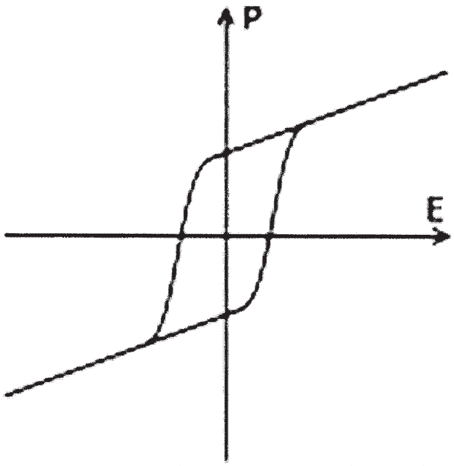

Fig. 4. Fero-magnetic polarization

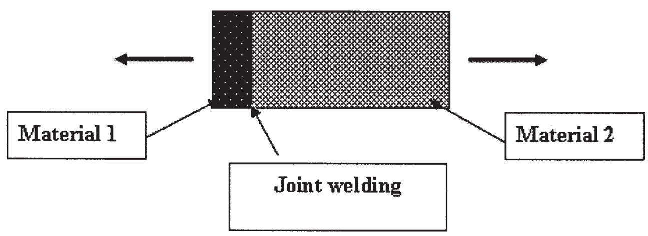

Fig. 5. The sketch of testing method

has as mandatory requirement to have the minimum breaking force 35N/50 mm, according to the sketch - picture 5 [6, 8].The measurement device for breaking force [6] was build up so that to respect the testing method requirement. This have a fix part, where is fixed the tested sample with a pin and a mobile slide with clamp parts, which slide through a screw- nut mechanism [6].

Evaluation and approaching of experimental results

For polymer welding ability study it there were used the data obtained during validation of HF welding process for 3 different products:

PVC with textile insertion 0.4± 0.1 mm (the structure according to figure 6)

Fig. 6. Structure of PVC with textile insertion

The HF welding parameters defined through experimental method for welding of auto sun-blinds from PVC with fabric insertion 0,4 ± 0,1 mm are:

Welding parameters	Parameters value
Welding power [mA]	5,0
Welding time [s]	2,2
Welding pressure [bar]	5,0
Cooling time [s]	2,0
Cooling pressure [bar]	5,0

After welding the parts must have visible welding steps (fig. 7) and the breaking force should be bigger than 35N/ 50mm.

Using the testing method described in preview paragraph, there were done measurements and records for 75 samples, cut from 25 welded parts from three defined areas.

According to the imposed quality norms [7], after destructive trials the distribution of melt material at macroscopic level have to be constant (fig. 8). The distribution of samples in welded part is presented in figure 9.

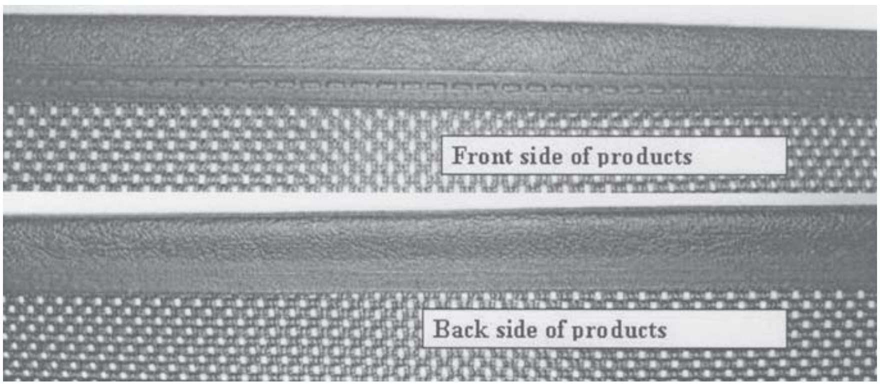

Fig. 7. Macroscopic appearance of welding part

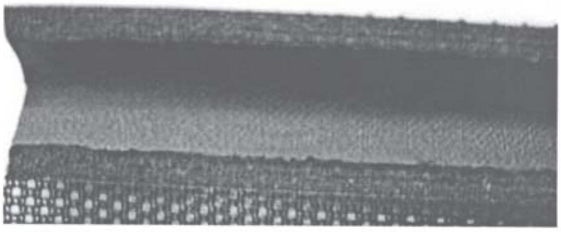

Fig. 8. The distribution of melt material in welding joint

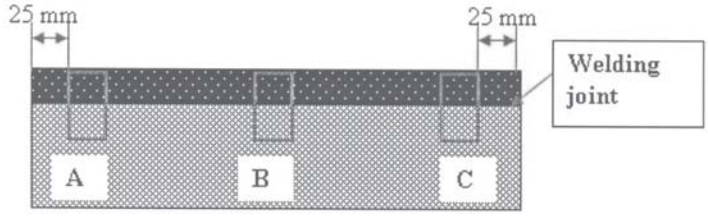

Fig. 9. Distribution of sample in welded part

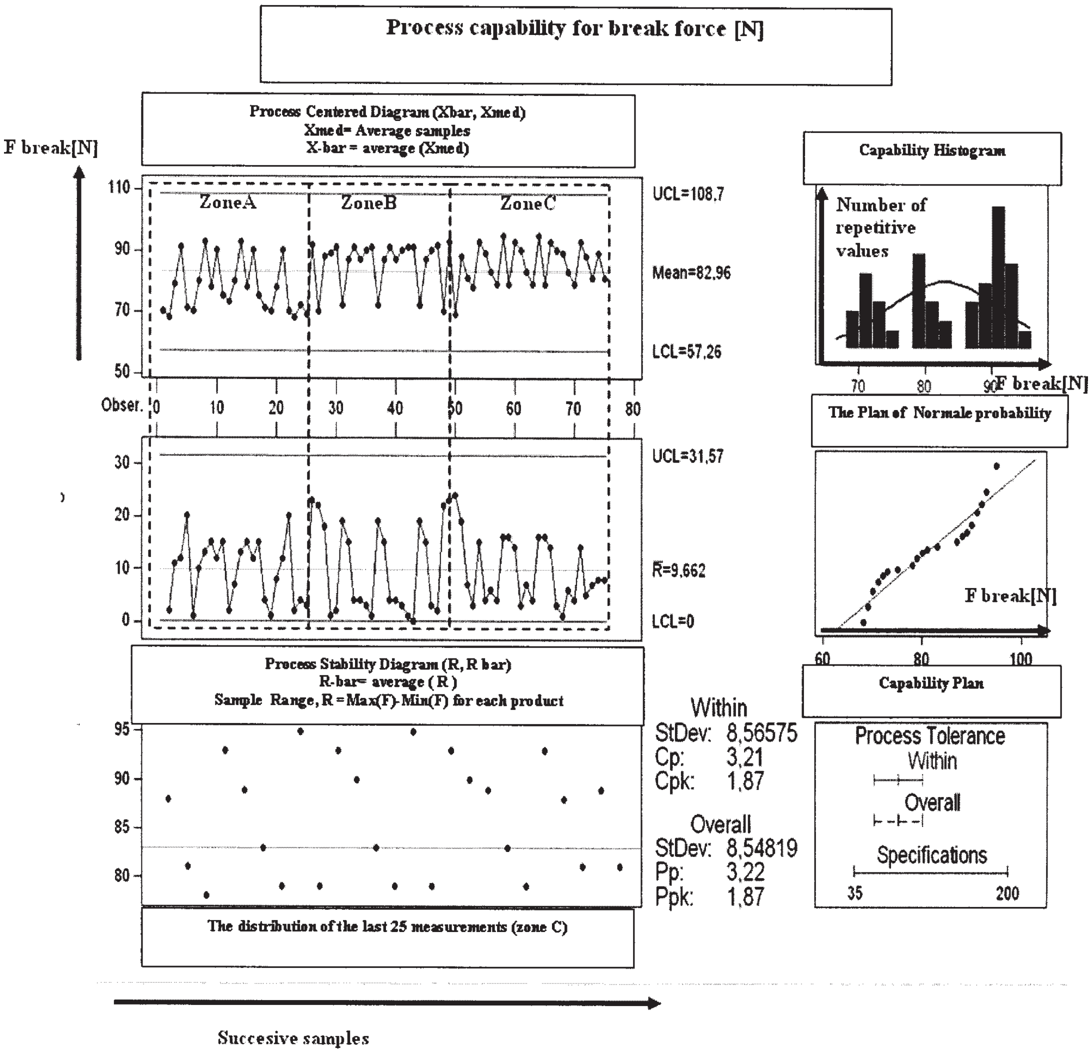

Fig. 10. HF welding process capability for PVC materials with fabric insertion 0,4 +/- 0,1
UCL= Upper control limit; LCL= Lower control limit

Using MINITAB software for statistical approaching of processes and the experimental data , there were obtained the process diagrams and the histogram from figure 10.

These values are statistical defined according to the number of samples and the recorded values of breaking force [6].

From capability histogram results a relatively uniform distribution for breaking force between 70- 90 N so we can conclude that the electrodes distribution along the welding tool influences the pressure on PVC material during the welding process and the mechanical characteristic values of welded joint area, in our case the breaking force.

The bigger the welding tool surface is, the higher is the influence on the mechanical parameters of the welding joints.

From centered diagram of the process (Xbar, Xmed), we can conclude that the HF welding process is stabile as adjustment, so with establish welding parameters are achieved the imposed requirements.

The process is stabile as precision according to stability diagram of the process (R, R bar).

The capability indicators are in target with 6σ ($Cp>1.67;Cpk>1.33$) limits [6]: $Cp = 3.21$; $Cpk = 1.87$

PVC with textile insertion 0.6 ±0.1 mm (the structure according to figure 6)

The HF welding parameters defined through experimental method for welding of auto sun-blinds from PVC with fabric insertion 0.6 ±0.1 mm are:

After welding the parts must have visible welding steps (fig. 11) and the breaking force have to be bigger than 35N/50mm.

Welding parameters	Parameters values	
	Welding step 1	Welding step 2
Welding power [mA]	2,5	4,0
Welding time [s]	2,0	5,0
Welding pressure [bar]	100	120
Cooling time [s]	6,0	6,0
Cooling pressure [bar]	140	140

Using the testing method described in previous paragraph, there were done measurements and records for 125 samples, cut from 25 welded parts from three defined areas in welding joint.

Fig. 11. The macroscopic appearance of welding part

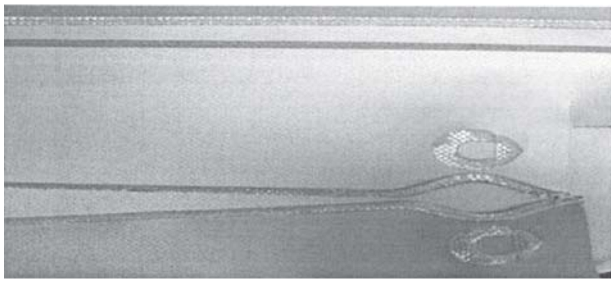

Fig. 12. The distribution of melt material in welding joint

After destructive trials the distribution of melt material at macroscopic level have to be constant (fig. 12) and the distribution of samples in welded part is presented in figure 13.

According to the experimental data and using MINITAB software for statistic analyses of the processes,there were obtained the diagrams from figure 14.

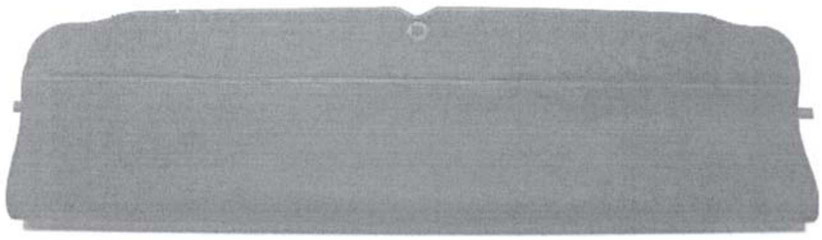

Fig. 13.Distribution of samples in welded part

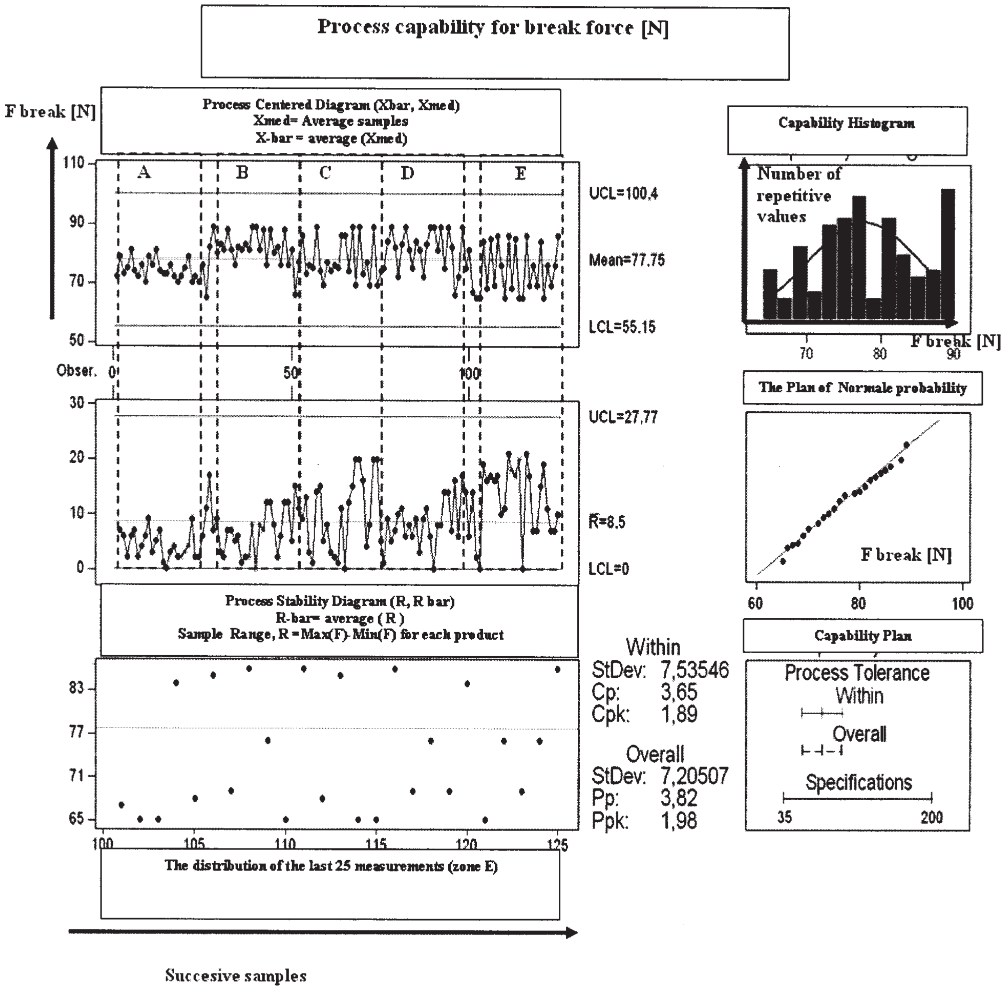

Fig. 14. HF welding process capability PVC materials with textile insertion 0.6 ±0.1 mm

The capability histogram shows a better distribution than previous example for breaking force between 66- 90 N, so the conclusion is that the electrodes distribution along the welding tool which influence the pressure on PVC material during the welding process and the mechanical characteristic values of welded joint area, in our case breaking force, is more stabile as the materials thickness increases.

From centered diagram of the process (Xbar, Xmed), we can conclude that the HF welding process is stabile as adjustment, so with welding parameters established are achieved the imposed requirements.

The process is stabile as precision according to stability diagram of the process (R, R bar).

The capability indicators are in target with 6s (Cp>1.67;Cpk>1.33) limits [6]: Cp = 3.65; Cpk = 1.89

Malivat 0,6 +/- 0,1 mm (structure according to picture15)

The HF welding parameters for welding of auto sun-blinds from Malivat material with one layer fabric on one layer PVC 0.6 0.1 mm had the values:

Fig. 15. Structure of MALIVAT: Fabric and PVC

After welding the parts must have visible welding steps (fig. 16) and the breaking force have to be bigger than 35N/50mm.

Welding parameters	Parameters value		
	Welding step 1	Welding step 2	Welding step 3
Welding power [mA]	2.5	4.0	5.0
Welding time [s]	1.0	2.0	3.0
Welding pressure [bar]	100	110	120
Cooling time [s]	6.0	6.0	6.0
Cooling pressure [bar]	140	140	140

The materials which have to be welded are distributed according to figure 17.

Using the testing method described in previous paragraph, it were done measurements and records for 75 samples, cut from 25 welded parts from three defined areas in welding joint.

After destructive trials the distribution of melt material at macroscopic level have to be constant (fig. 18) and the braking force diagrams are presented in figure 19.

Using MINITAB software for statistical approaching of processes and the data from experiments there were obtaining the process diagrams and the histogram from figure 19.

From capability histogram results a relatively uniform distribution for breaking forces between 100- 150 N. The

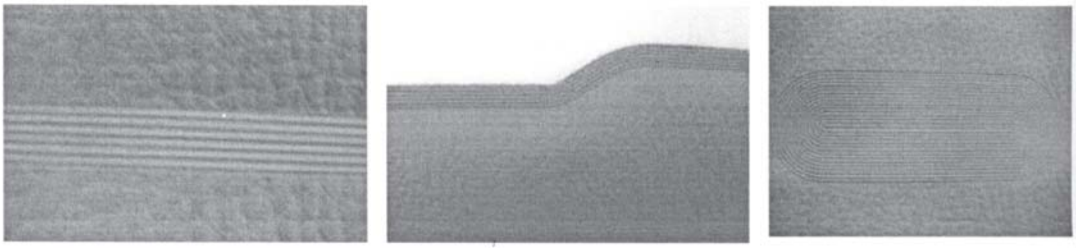

Fig. 16. The macroscopic appearance of welding part

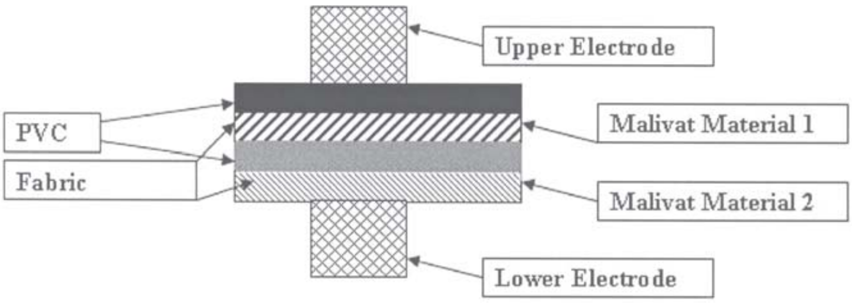

Fig. 17. Distribution of MALIVAT materials during HF welding

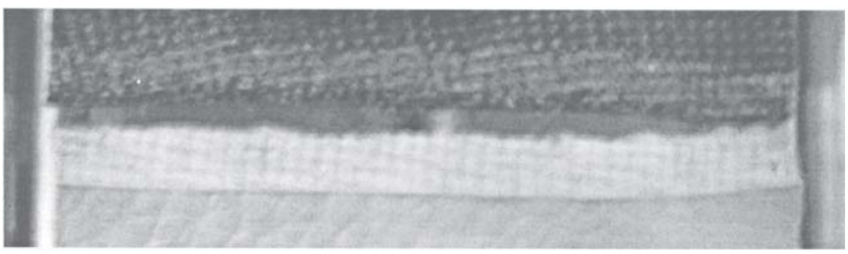

Fig. 18.Distribution of melt material in welding joint

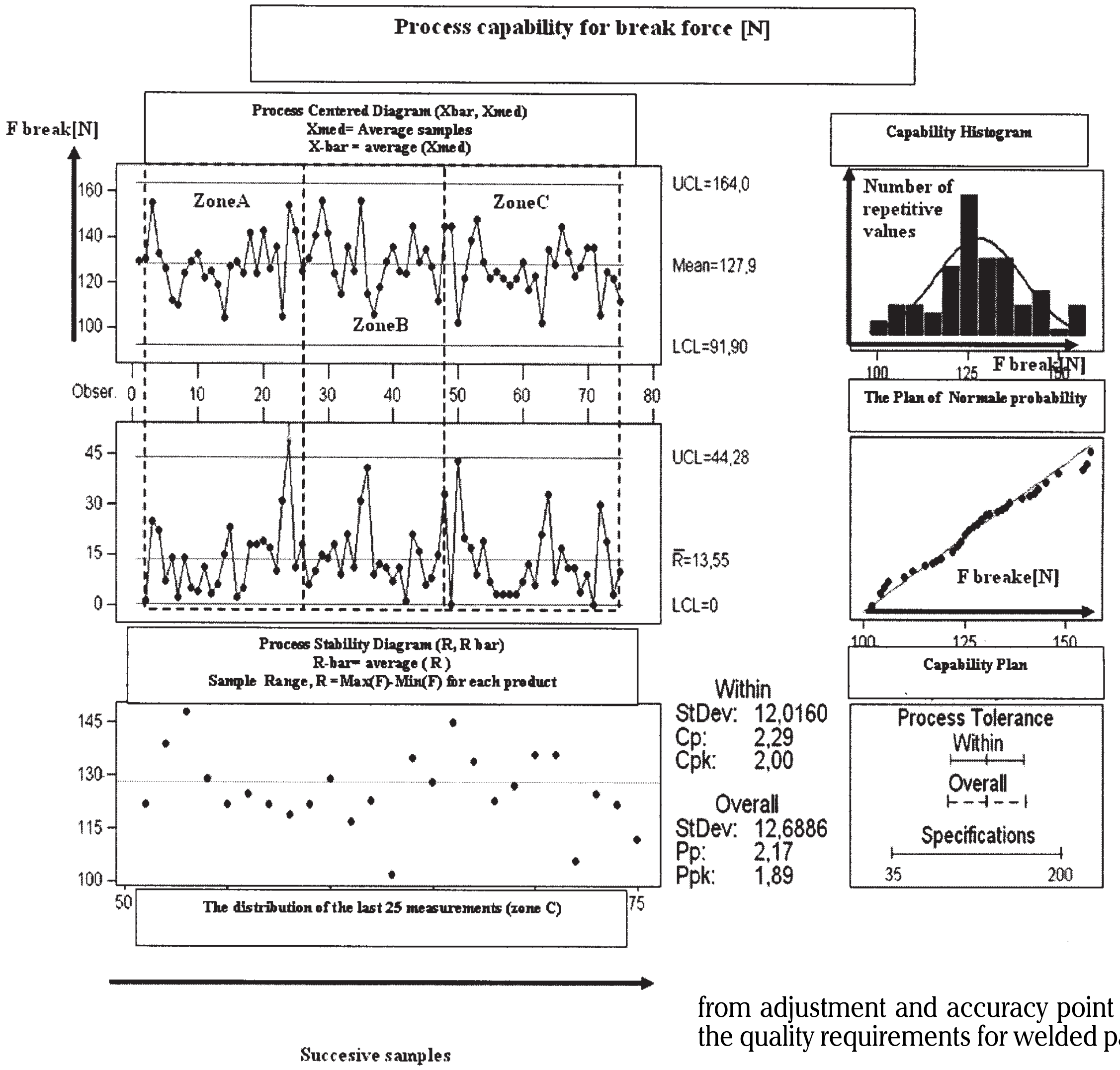

Fig. 19. HF welding process capability of malivat materials 0.6 ±0.1 mm

breaking force is bigger for Malivat materials than for PVC materials with fabric insertion.

The advantage of this material is that it is cheaper because we have only one side covered with PVC.

From centered diagram of the process (Xbar, Xmed), we can conclude that the HF welding process is stabile as adjustment, so with welding parameters establishd are achieved the imposed requirements.

The process is stabile as precision according to stability diagram of the process (R, R bar).

The capability indicators are in target with 6σ (Cp>1.67;Cpk>1.33) limits [6]: Cp = 2.29; Cpk = 2

Conclusions

The capability histogram of breaking force of welding joint shows a better distribution with increase of welding and cooling pressures applied during the process, these compensate the electrodes level differences along the welding tool.

To obtain similar breaking forces of welded joint for different thickness of materials which have to be welded it is suggested a usage of harder welding parameters.

For lower influences of molecular structure of PVC, with materials thickness increase it is recommend to be used the welding in more steps, and in this case is avoided the disintegration of materials, which may cause electrical short circuit.

The experimental established technological parameters for HF welding for PVC prove that this process is stabile from adjustment and accuracy point of view, respecting the quality requirements for welded parts.

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References

1.BARON T., ISAC-MANIU AL.:,Calitate si Fiabilitate, p.90...153, 336...470, Ed. Tehnica Bucuresti, 1988

2.JACSCH E., CHETARITI D., Materiale plastice poliamidice, Ed. Tehnica Bucuresti, 1988

3.LORENSCHEIT K. : Hoch Frequenz Technik, Verlag, Mainz 1997/1998

4.BARON T., Metode statistice pentru analiza si controlul calitatii productiei, Ed. Tehnica Bucuresti, 1988, p. 270...292

5.MITELEA I., TILLMANN W. , Ştiinţa materialelor II, p.269...300, Editura Politehnica Timişoara, 2007

6.MITELEA, I., VĂRZARU, N., POPOVICI, D., POPESCU, M., BORDEAŞU, I., Mat. Plast., **45,** nr. 3, p. 221

7.SR ISO/TS 16949:2002, Editia 1, ASRO Bucuresti, p.40…48

8.*** Normalisation Renault Automobiles - Renault V.I. Service 60201 Section Normes et Cahiers des Charges: Norm 1033- Shearing Stengh of HF Welds Textiles- Plastic Sheets, Plastic- Coated Textiles, Revision February 1987 , p.2...5.

9.VODĂ, M., BORDEAŞU, I., MESMACQUE, G., CHIŢAC, V., TABĂRA, I., Mat. Plast., **44**, nr. 3, 2007, p. 254

10.IANCAU, H., BERE, P., BORZAN, M., HANCU, L., CRAI, A., Mat. Plast, **43**, nr.3, 2008, p.251

11.HARAGAS, S., TUDOSE, L., STANESCU CRISTINA., Mat.Plast, **45**, nr.1, 2008, p.53

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