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Analysis of High-Frequency Artificial Leather Welding as a Function of Seam Quality

Abstract
The basic properties of the high-frequency welding of garment pieces are presented. The impact of artificial leather properties on the quality and strength of high-frequency welding was explored. The weld quality and strength of different artificial leather samples were optimised by regulating the temperature, power and duration of welding. Based on the results obtained, it may be claimed that parameter changes in the welding process, as well as changes in the technological process of manufacturing artificial leather, in the raw material composition, coating component portions and colour of the polyurethane coat (PU) directly affect the quality, strength and water impermeability of the seam.

Key words: *high-frequency welding, artificial leather, polyurethane coating.*

Introduction

Artificial polymer materials are gaining in importance in the manufacture of garments for use as protection against wind, rain, sun etc. Such multiple-component materials belong to the group of composite materials or to the group of technical textiles. The development of this kind of textile has been prominent over the last several decades, and its growth is continual. Likewise, the types and applications of composite materials continually develop, but they are not only used for making articles of clothing - they are also encountered in different branches of industry. For example, they are used in medicine, as car seat covers in public buildings, in civil engineering, agronomy, sports etc. They are very interesting for clothing articles because they can be adjusted to wearing conditions, and at the same time they are comfortable. The multiple-component materials used for making garments must contain target properties: impermeability to water, wind, UV-radiation, abrasion resistance; at the same time they should be comfortable, transparent, soft, elastic and pliable. Artificial leather consisting of a textile substrate and PU coating is often used for protective clothing against foul weather. It is not enough to make a fabric with satisfactory properties, but also to join the cut parts qualitatively. It is desirable that at the joint no water and air are allowed to pass through, which is not possible with classic sewn seams since they are used for spot welding. Therefore, it is necessary to join cut parts in such a way that the materials are glued at the joint. This kind of welding is possible in several ways. One of the most qualitative and reliable procedures is high-frequency welding, which is analysed in this paper [1 - 3].

There are several joining methods for artificial leather: The sewn seam, thermal, ultrasonic and high-frequency welding methods are the most widely used in the clothing industry for joining artificial leather.

Artificial leather is joined using sewing machines when the finished product does not require impermeable joints, e.g. for car seat covers, while powerboat covers do. Through good selection of the seam type, machine sewing stitch, needle and sewing thread, it is possible to make joints of a specific strength and elasticity [4].

Thermal joining involves the heating of material to a softening temperature and permanent joining through the application of a force on a certain surface. The low thermal conductivity of polymeric materials is a special problem because they quickly heat up on the surface, with their inside remaining cold [5, 6].

The ultrasound joining machine consists of four main components: a generator, transducer, amplifier and rollers.

Instead of a mechanism for making machine sewing stitches, there is an ultrasound transducer in the sewing machine head, which converts the alternating voltage of the ultrasound generator into mechanical oscillations. The oscillation amplitude is additionally enhanced in the amplifier, and the sonotrode guides it to the material to be joined. Mechanical oscillations of a relatively high frequency act on macromolecules, compelling them to movement as well as to the partial disruption and re-establishment of intermolecular bonds, which results in heat development. When the material heats up, a pressure of relatively low force is enough to join the materials permanently [6, 7].

The high-frequency welding technique is used to join artificial polymer materials that consist of macromolecules with prominent polarization, thus having a prominent electrical charge in some of their parts. Molecules are polarised in the electric field according to the direction of the lines of force.

By connecting high-frequency voltage molecules within the material, it starts vibrating, which results in the occurrence of heat over the whole volume of the material to be welded.

A great advantage of high-frequency welding is the speed of this procedure; since heat occurs within the material at the same time as on the surface, welding occurs in a few seconds. In the case of other welding types, heat is conducted to the material from outside, meaning that it must first penetrate into the material followed by welding [8 - 10].

In the process of high-frequency welding, there are several parameters which should be appropriately adjusted in order to achieve an optimum material weld: the power, pressure of the electrode, and the welding duration. Welding power depends on the material type and thickness, the number of layers to be welded, the electrode length and shape, electrode insulation and working surface. If the material is thicker, higher welding power should be applied. As a rule, higher power is necessary for a longer electrode. The pressure of the electrode acts on the material, where it is important that the pressure is optimal and uniformly distributed along the whole electrode. In the case of too high a pressure, the electrode penetrates too deeply into the material, too much power is transferred to the welding place, and the material becomes too thin, resulting in a reduction in the weld strength or material damage. On the other hand, if the pressure of the electrode is insufficient, it will not press the material enough, and the weld will not have satisfactory strength, or the material layers will not be welded.

After adjusting the welding parameters, a visual inspection of the seam strength is performed, where the seam must not stretch at the beginning or at the end, only in the middle. If the seam satisfies visual inspection when under manual stretching, water impermeability testing follows. The purpose of this paper is to investigate the influence of material properties on joint quality.

Experimental

High-frequency welding was employed to join the samples on a Radyne welding machine using a 15 cm long and 4 mm thick electrode coated with Teflon material. By variation of the parameters on the high-frequency welding machine, their impact and correlation with the breaking force and water impermeability of the welded place were tested.

Samples were made of artificial leather with changes in the coating composition and conditions of the coating process. The high-frequency welding technique was used to weld garment parts, and by varying the parameters on the high-frequency welding machine, their impact and correlation with the water impermeability and strength of the welded place were tested [11].

Materials

In addition to the influence of material properties on the joint quality, this paper will deal with the optimal conditions of joining the samples with a different composition of coating and varying material stiffness. Tests were performed on artificial leather, and a white antibacterially treated weft-knitted fabric (PA 6.6) was used as the substrate for coating. The data in ***Table 1*** were obtained by testing the properties of the knitted fabric used as the substrate for the coating.

Three different samples of artificial leather in two colours were used for testing. Samples I and II were different in Vithane additives: Sample I had S20 as an additive, while samples II and III had ACR as an additive. The difference between samples II and III is in the material stiffness - sample III is stiffer. All three samples were made in two colours (blue and yellow). Twenty samples without a welded place were made for testing. The welded places were divided into 21 groups which differ in time (s) and power (W) (***Table 1***). In each group 20 samples were tested. The breaking force and water impermeability of the welded seams were tested.

PU polymers, additives and binders as well as their properties used in making

Table 1. *Results of testing technical characteristics of the knitted fabric; x - mean value, CV – coefficient of variation.*

Tested parameters		Knitted fabric	
		x	CV, %
Elongation at break in the width direction (in warp direction), *%*		71	2.82
Elongation at break in the cross direction (in weft direction), *%*		105	1.90
Breaking force in the width direction, *N*		331.42	3.03
Breaking force in the cross direction, *N*		157.06	3.69
Density, *threads / 1 cm*	wales	***12***	24.8
	courses	13	21.7
Raw material composition		Polyamide 6.6	
Knitted fabric width, *cm*		164	
Surface mass of the knitted fabric, *g/cm²*		86	
Knitted fabric thickness, *mm*		0.5	
Yarn count, *tex*		7.8	

Table 2. *Components of the coating, polymers, additives, binders and their properties.*

Name	Type	Form	Property
Larithane MS 132	Aromatic polyester	Colorless solution	Resistance to friction
Laripur 065/85	Polyester	Slightly yellow chips	Easy stretching
Sanitized TPL 20-2	Additive	Yellow-brown solution	Antimicrobial and antifungicidal action
Vithane S20	Modified silicone polymer	Colorless solution	Good coat uniformity
Vithane ACR		Turbid solution	Good coat uniformity
Tinuvin 765	Additive	Slightly yellow solution	Resistance to light and UV radiation
Larithane MA 80	Aromatic polyester binder	Colorless solution	It allows gluing the coat and knitted fabric, good resistance to hydrolysis
Larithane CL 1	Aromatic cross-linking agent	Solution	Good binding properties, high stability to hydrolysis and washing
DMF	Solvent		

***Table** 3. Agents and pigments applied, as well as the distance between the rollers and paper for each sample (h in mm).*

Samples		Agents			Pigments per colors		h, mm
		Name	Portion, %		Name	Portion, %	
			Blue	Yellow			
I	Blue	Vithane S20 Larithane MS 132 Laripur 065/85 Sanitized TPL 20-2 Tinuvin 765 DMF	0.18 31.03 44.33 0.17 0.53 13.30	0.18 30.70 43.85 0.18 0.53 13.16	Pigments –S S1251 (Blue) S1052 (Black) S1153 (Pink) S1001 (White)	5.32 1.77 0.71 2.22 0.45	0.65
	Yellow				Pigments –S S1858 (Yellow) S1152 (Red)	5.26 6.14 0.01	
II	Blue	Vithane ACR Larithane MS 132 Laripur 065/85 Sanitized TPL 20-2 Tinuvin 765 DMF	0.88 30.81 44.01 0.18 0.53 13.21	0.87 30.49 43.55 0.17 0.52 13.06	Pigments –S S1251 (Blue) S1052 (Black) S1153 (Pink) S1001 (White)	5.28 1.76 0.70 2.20 0.44	
	Yellow				Pigments –S S1858 (Yellow) S1152 (Red)	5.23 6.10 0.01	
III	Blue	Vithane ACR Larithane MS 132 Laripur 065/85 Sanitized TPL 20-2 Tinuvin 765 DMF	0.88 30.81 44.01 0.18 0.53 13.21	0.87 30.49 43.55 0.17 0.52 13.06	Pigments –S S1251 (Blue) S1052 (Black) S1153 (Pink) S1001 (White)	5.28 1.76 0.70 2.20 0.44	0.50
	Yellow				Pigments –S S1858 (Yellow) S1152 (Red)	5.23 6.10 0.01	

Table 4. Varying conditions in the high-frequency welding process and a description of the seam.

Samples	Duration, s	Power, W	Seam appearance		
			Sample 1	Sample 2	Sample 3
0	3	3080	No mark	No mark	No mark
	4				
	5				
	3	3115			
	4				
	5				
	3	3150	Weak mark, seam disintegrates		Weak mark, seam disintegrates
	4				
	5			Weak mark, seam disintegrates	
	5			Weak mark, seam disintegrates	
	3	3185	Stronger mark, when stretching holes in the seam visible		
	4				
1	3	3220	the seam looks satisfactory		
2	4				
3	5				
4	3	3273			
5	4				
6	5				
7	3	3290			
8	4				
9	5				
10	3	3360			
11	4				
12	5				
13	3	3395			
14	4		Very strong mark, the seam looks satisfactory		
15	5				
16	3	3465	The seam looks satisfactory		
17	4		Very strong mark, the seam looks satisfactory		
18	5				
19	3	3500	The seam looks satisfactory		
20	4		Very strong mark, the seam looks satisfactory		
21	5				

the samples are illustrated in ***Table 2***. Agents, pigments and the distance between rollers and paper for each sample are shown in ***Table 3***.

Test conditions

The welding power and time of reaction of high-frequency welding on the appearance of the seam of each sample were tested (***Table 4***). When the reaction time of the high-frequency welding was extended from 3,080 W to 3,185 W, the seam did not look acceptable. The seam looked visually acceptable for all samples just above 3,222 W. With an increase in power (up to 3.500 W), the seam looked good, but the seam quality can only be determined by measuring the breaking force and water impermeability. If the welding process is with a power higher than 3,390 W lasting above 3 seconds, too strong a mark occurs and the welded place is too weak, hence it was decided not to exceed 3 seconds of welding.

The breaking forces and elongation at break were tested according to Standards ISO 1421:1998 & EN ISO 1421:1998. Tests were performed on a Thuringer Industriewerk Raustein tensile tester, which works on the principle of constant drawing speed. The distance between the clamps was adjusted to 200 mm. The loading or drawing speed was adjusted in such a way that a break occurred within 60±10 s or the movement speed of the bottom clamp amounted to 100 mm/min. Breaking forces and elongation at break of samples with a welded place were tested according to the standards ISO 13935-1.

The resistance to water penetration was tested according to Standard ISO 811 on a Pfaff water impermeability tester. The coefficient of resistance to water penetration represents the pressure relationship when the first drop of water penetrates the sample. Tests of high-frequency welding were carried out on a Radyne machine.

Evaluation of mechanical properties

Five samples for each test condition were used to investigate their mechanical properties. Three persons individually carried out a visual assessment of the seam in ***Table 4***. When comparing the assessments made by the three persons, no substantial differences were noticed. In the case of conditions of 3150 and 3395 W (***Table 4***), slight differences in the assessments were found, and following a mutual agreement, an appropriate assessment was given.

Results and discussion

According to the results obtained, given in ***Tables 4*** to ***9*** and ***Figures 1*** to ***4***, a difference in properties between seamed and seamless samples can be found. A change in parameters when joining a seam affects the quality of the strength of the joint.

Table 4 shows that the parameters changed during welding as well as the

Table 5. Test values of samples I, II and III without a joint; x - mean value, CV – variation coefficient.

Tested parameters	Sample I				Sample II				Sample III			
	Blue		Yellow		Blue		Yellow		Blue		Yellow	
	x	CV, %	x	CV, %	x	CV, %	x	CV, %	x	CV, %	x	CV, %
Mass per unit area, g/cm^2	163	2.43	167	1.89	167	0.79	168	1.06	170	1.25	172	0.98
Sample thickness, mm	0.49	0.02	0.49	0.01	0.47	0.02	0.47	0.02	0.46	0.025	0.46	0.03
Longitudinal load at break, N	461.23	2.77	434.81	4.65	487.21	2.37	466.80	3.76	510.52	1.96	490.44	2.04
Transverse load at break, N	203.32	3.47	177.35	3.33	216.01	3.77	203.41	2.66	230.47	2.84	219.51	2.79
Elongation at break in the length, %	106.00	1.89	98.67	1.17	110.00	0.91	103.67	0.56	98.00	1.02	87.00	2.30
Elongation at break in the width, %	250.33	0.80	237.33	0.24	269.00	0.42	223.02	0.38	235.17	0.43	250.10	0.69
Water impermeability, kPa	50.41	12.31	51.25	16.15	51.51	8.51	52.01	10.66	52.71	13.5	53.43	11.44

visual appearance of the seam for an individual condition. On the basis of good visual appearance and satisfactory strength examined by the manual stretching of the seam, conditions were chosen which provide satisfactory criteria, and samples were made under those conditions for subsequent investigations.

Table 5 shows the physical and mechanical parameters of the seamless samples tested. According to the results obtained, it can be claimed that the mass per unit area differs for each sample and colour. It is noticeable that the yellow samples have a higher mass per unit area. Sample III, which differs from the other two in its stiffness, has the highest mass per unit area.

This means that a smaller gap caused a higher mass pressureand penetration of the coating into the knitted fabric, hence the first layer of the coating partially or completely filled the yarn and fiber interstices in the knitted fabric, resulting in an increase in the total coating. The other parameters tested, such as the sample thickness, breaking strength and impermeability to water justify this statement. The coefficient of variation of the mass is the highest for sample I, where the additive Vithane S20 is contained in the coating, meaning that it does not generate the same homogenisation of the coating as the Vithane ACR contained in the coating of samples II and III.

The thickness of each sample differs, but within the samples the colour is the same. Sample I has the greatest thickness, while sample III has the lowest, which also has the smallest gap when the agent is applied to the knitted fabric (***Table 4***).

The average values of the longitudinal forces of the samples tested are almost twice as high as their transverse forces (***Table 5***).

Sample III has the highest breaking forces, followed by sample II and then sample I, with the lowest force. It is important to note that the blue samples have a higher breaking force than the yellow ones for all samples in both directions tested; although the mass per unit area is higher for the yellow samples. Sample thickness differs per sample, but there is no difference with respect to colour. The elongation at break did not always follow the course of breaking forces. It can be noted that the elongation at break is always several times higher in the sample width. Water impermeability is higher in the yellow samples, which also had

Table 6. *Results of testing the breaking force and water impermeability of the joint for sample I; t – duration of welding, S – power.*

Sample	Conditions	Breaking force, N				Elongation at break, %			
	t, s / S, W	Blue		Yellow		Blue		Yellow	
		x, N	CV, %	x, N	CV, %	x, %	CV, %	x, %	CV, %
1	3/3220	44.99	1.30	43.78	1.35	157.88	2.10	187.31	1.05
2	4/3220	47.29	1.22	48.58	1.19	141.70	1.84	219.72	1.53
3	5/3220	56.58	1.02	88.20	0.65	200.72	2.88	220.51	1.77
4	3/3273	54.92	2.13	61.30	0.94	141.63	2.14	211.09	1.22
5	4/3273	56.77	2.07	48.55	1.19	133.66	2.00	227.91	1.92
6	5/3273	64.29	0.91	64.29	0.91	141.99	1.99	225.86	2.06
7	3/3290	89.29	0.07	114.19	0.88	117.82	2.19	189.33	2.17
8	4/3290	140.88	1.43	128.97	2.04	132.01	1.56	200.74	1.78
9	5/3290	146.49	0.40	133.29	0.35	158.41	1.94	261.99	2.73
10	3/3360	91.59	1.27	78.39	0.74	155.29	2.30	240.77	1.88
11	4/3360	148.75	0.42	165.33	0.35	167.29	2.44	251.03	2.68
12	5/3360	199.71	0.78	187.80	0.61	180.20	2.27	266.01	2.81
13	3/3395	171.33	0.58	103.49	0.56	158.72	2.38	261.88	2.73
14	4/3395	178.91	3.91	128.99	1.55	144.99	2.10	278.04	2.56
15	5/3395	98.00	2.50	83.50	1.89	109.45	1.88	181.06	2.11
16	3/3465	87.29	0.67	94.91	0.56	155.26	2.00	226.89	1.77
17	4/3465	113.00	3.90	96.77	1.29	115.81	1.58	171.42	1.91
18	5/3465	98.02	4.55	81.18	3.91	98.54	2.77	114.00	2.71
19	3/3500	49.69	2.04	107.65	0.54	162.17	2.62	197.08	2.00
20	4/3500	89.55	2.33	82.09	1.55	120.47	2.18	225.71	1.88
21	5/3500	28.91	5.32	31.77	4.21	113.22	3.72	110.32	2.16

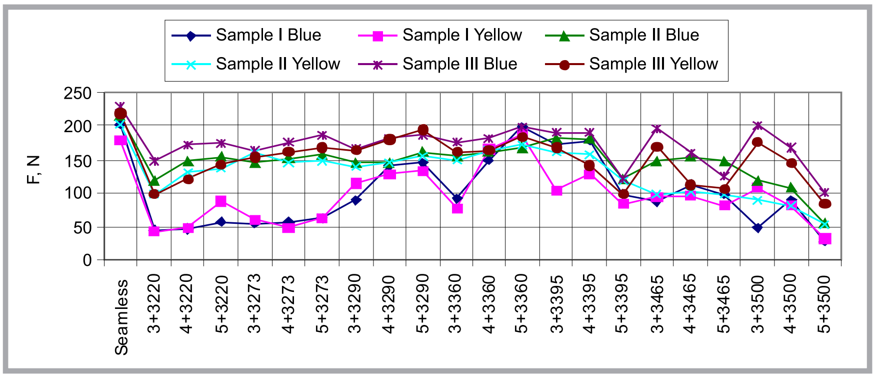

Figure 1. *Breaking forces of samples and colors; F – breaking force in N, 3+3320 – time in s + power in W.*

a higher mass per unit area. Sample III, which is stiffer because the coating is more strongly pressed into the substrate, has the greatest water impermeability.

The breaking force of each sample changed as a result of varying the welding conditions of the material (***Tables 6*** to ***8, Figures. 1*** and ***2***). Tests were made during welding after 3, 4 and 5 seconds using power of 3220, 3273, 3290, 3360, 3395, 3465 and 3500 W. In most cases the colour blue has a higher breaking force than yellow for all samples and the same welding conditions. By increasing the duration of seam welding, the breaking force also increases, but from 3220 W to 3360 W. Above 3360 W, for all samples and colours, the breaking force does not increase with the duration of welding a seam. Sample III has the highest average breaking force, followed by sample II, while sample I has the lowest average breaking force. Furthermore, there is an obvious difference between the breaking forces of sample I compared with those of samples II and III, even at lower power (up to 3273 W etc.), meaning that the power in W greatly affects the breaking forces, while the welding time does not affect them to such an extent, probably because of the time difference (1 to 5 seconds).

When the samples are studied separately, then we can observe that sample I in blue has a breaking force in the range of 28.91 N (5 / 3500) to 199.71 N (5 / 3360) (***Table 6, Figure 1***). The samples in yellow have a breaking force of 31.77 N (5 / 3500) to 187.8 N (5 / 3360). The coefficient of variation of the breaking

***Table 7.** Results of testing the braking force and water impermeability of the joint in sample II; t – duration of welding, S – power.*

Sample	Conditions	Breaking force, N				Elongation at break, %			
	t, s / S, W	Blue		Yellow		Blue		Yellow	
		x, N	CV, %	x, N	CV, %	x, %	CV, %	x, %	CV, %
1	3/3220	118.37	0.85	98.33	1.02	216.72	0.31	221.64	0.42
2	4/3220	146.79	0.39	130.35	1.17	187.91	0.28	220.10	0.48
3	5/3220	154.27	0.65	138.00	0.72	232.71	0.44	231.19	0.66
4	3/3273	146.00	0.39	160.33	1.57	179.00	1.00	209.11	0.99
5	4/3273	150.91	0.11	145.08	1.05	188.82	0.78	242.52	0.51
6	5/3273	157.02	1.27	147.18	0.39	176.72	0.98	187.51	0.52
7	3/3290	145.72	0.69	139.63	1.44	180.04	0.55	196.34	0.50
8	4/3290	145.70	0.40	145.22	0.54	188.39	0.21	199.30	0.95
9	5/3290	161.19	0.62	155.18	0.50	192.05	0.92	193.20	0.32
10	3/3360	154.88	0.72	150.54	0.87	189.99	1.01	198.32	0.71
11	4/3360	161.11	0.62	164.56	0.61	212.74	0.33	225.61	0.35
12	5/3360	168.08	1.19	172.77	0.55	200.61	0.25	240.19	0.33
13	3/3395	182.53	0.32	162.10	0.36	186.79	0.21	221.88	0.42
14	4/3395	180.72	0.43	158.32	1.22	170.21	0.89	177.29	0.81
15	5/3395	121.45	1.21	119.28	0.94	116.32	1.29	135.60	1.30
16	3/3465	146.55	0.39	98.66	1.02	132.82	1.09	156.88	0.28
17	4/3465	153.00	2.91	102.42	1.71	148.32	1.32	149.00	1.32
18	5/3465	147.39	0.78	98.02	2.30	110.20	1.48	121.80	1.56
19	3/3500	118.09	0.85	90.77	0.64	131.05	0.72	147.21	0.37
20	4/3500	109.02	2.68	82.10	4.09	100.32	1.78	98.80	2.67
21	5/3500	54.71	5.89	52.81	6.39	110.34	3.50	88.54	3.03

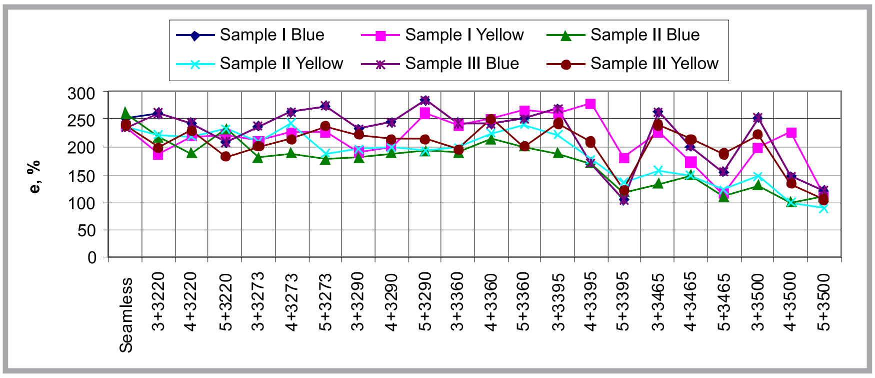

***Figure 2.** Elongation at break of samples and colors; ε – elongation at break in %, 3+3320 – time in s + power in W.*

force is relatively small, ranging from 0.07% to 5.32%. The elongation at break is usually higher for the samples in blue (***Table 6, Figure 2***). The breaking elongation is relatively high in all samples, ranging from 98.54% to 278.04%, with a relatively small coefficient of variation, ranging from 1.05% to 3.72%.

The breaking force of sample II is also, in most cases, higher in the blue samples, ranging from 54.71 N (5 / 3500) to 182.53 N (3 / 3395) (***Table 7***). The sample in yellow has a breaking force from 52.81 N (5 / 3500) to 172.77 N (5 / 3360). The coefficient of variation of the breaking force is also relatively small, ranging from 0.11% to 6.39%, but with a greater variation in samples I and III. The elongation at break is also relatively large, ranging from 100.32% to 242.52%, with a coefficient of variation from 0.21% to 3.50% (***Table 7, Figure 2***).

The breaking force of sample III in blue ranges from 100.93 N (5 / 3500) to 201.4 N (3 / 3500), while for the same samples in yellow it ranges from 83.95 N (5 / 3500) to 195.52 N (5 / 3290) (***Table 8, Figure 1***). The elongation at break in blue ranges from 105,00% to 283.29%, while the elongation at break in yellow ranges from 105.20% to 250.05%. The coefficient of variation of the breaking force is uniform, and there is no difference between the colours, ranging from 0.00% to 1.97%, while in the case of the elongation at break it ranges from 0.79% to 3.92% (***Table 8, Figure 2***).

Figure 1 shows that sample I often has the lowest breaking force, especially in the case of a lower stress for seam welding. Samples II and III have very similar values, but sample III often has a higher breaking force nevertheless.

It is worth emphasising that water impermeability is often higher in seamed samples compared to seamless ones, the reason for which is the way of testing seamed samples, in which the seam runs across the middle of the circular sample, whereby a piece of material at the seam will triple the material strength of the sample in this part. It is worth pointing out that these differences are not large. The water impermeability of the samples varies both between the samples and within each sample (***Table 9***). Thus, the conditions of seam welding affect water impermeability. According to the results obtained, it cannot be claimed that water impermeability is greater or lower in one colour; values vary between colours, and it can be stated for sample I that at a lower stress higher water impermeability prevails in a yellow colour, while at a higher stress water impermeability prevails in a blue color. The lowest water impermeability exists in sample I in yellow, amounting to 40.32 kPa (5 / 3500), while the highest water impermeability occurs in a blue colour, amounting to 70.31 kPa (5 / 3290).

The water impermeability of sample II changes for each sample and colour. According to the results obtained, it can be ascertained that it is higher for the colour blue. The lowest water impermeability for sample II is in the blue sample, amounting to 40.21 kPa (5 / 3500), and the highest water impermeability is also in the colour blue, amounting to 77.82 (5 / 3395).

For sample III water impermeability also changes according to the conditions of seam welding. According to the results obtained, it can also be ascertained that sample III mostly has higher water impermeability in blue samples. The values of water impermeability in sample III ranges from 42.40 kPa (3/465) in yellow to 75.88 kPa (5/3360) in blue (***Table 6, Figure 3***). The coefficient of variation of water impermeability changes in accordance with the conditions of seam welding and cannot be determined from the difference between the samples or within the samples themselves, ranging from 8.44% (3/3395) for sample I in blue to 16.30% (3/3360) for sample II in yellow.

As regards the average values of water impermeability, no greater deviations are seen among the samples, ranging from

52.03 kPa for sample II in yellow to 56.42 kPa for sample III in blue.

According to ***Figure 3***, water impermeability is very similar at a higher and lower stress of seam welding, while the deviation is higher at a medium stress.

Figure 4 shows the relationships of the breaking forces of the seamed and seamless samples. In the results, deviations of the breaking forces of the seamed samples can be seen. The highest deviation of the breaking forces of the seamed samples was in those with a breaking force of 203.41 N (sample II in yellow) and 203.32 N (sample I in blue), whereas the lowest deviation was at a breaking force of 230.47 N (sample III in blue).

Figure 5 shows the relationship between the breaking forces and water permeability of the samples with a seam. In the the results obtained, the distribution of group points can be seen, mostly between breaking forces from 50 N to 200 N and water impermeability values between 40 kPas and 80 kPas. Only because of this dispersion of values can it be concluded that there is no strong linear relationship between the breaking force and water impermeability of the materials, but it is possible to limit the area where the values most frequently appear. In addition, we can see that the surface decreases and falls to the abscissa at higher values of water impermeability.

Table 8. *Results of testing the breaking force and elongation at break of the joint in sample III.*

Sample	Conditions	Breaking force, N				Elongation at break, %			
	t, s / S, W	Blue		Yellow		Blue		Yellow	
		x, N	CV, %	x, N	CV, %	x, %	CV, %	x, %	CV, %
1	3/3220	148.23	0.39	97.42	1.03	261.92	1.00	198.66	0.99
2	4/3220	172.81	0.34	120.36	0.48	242.01	1.79	230.55	1.26
3	5/3220	175.19	0.33	144.21	0.44	208.12	1.67	183.20	1.18
4	3/3273	164.70	0.61	153.83	0.00	236.22	2.05	199.82	0.79
5	4/3273	176.27	0.57	161.72	0.36	264.71	2.91	213.67	1.48
6	5/3273	185.52	0.31	168.69	0.34	273.62	1.45	237.09	1.04
7	3/3290	165.51	0.09	163.65	0.35	231.29	2.03	222.01	1.05
8	4/3290	181.42	0.32	179.62	0.32	245.53	2.71	214.44	1.76
9	5/3290	185.61	0.54	195.52	0.78	283.29	1.77	212.66	1.33
10	3/3360	176.78	0.33	162.09	0.36	242.41	1.65	196.42	0.79
11	4/3360	182.29	0.32	164.82	0.35	243.22	1.15	250.05	1.11
12	5/3360	198.47	0.29	184.18	0.37	250.99	2.00	200.29	0.92
13	3/3395	191.42	0.50	168.72	0.29	267.89	3.00	242.62	2.73
14	4/3395	191.11	0.71	140.55	0.38	170.31	3.85	209.00	2.55
15	5/3395	120.67	0.99	97.72	1.97	105.00	3.77	122.58	3.05
16	3/3465	197.27	0.58	170.70	0.34	264.33	2.78	239.67	2.16
17	4/3465	160.33	1.23	113.49	1.55	201.21	2.00	213.98	1.77
18	5/3465	125.66	0.69	107.04	1.63	154.07	2.13	188.60	1.93
19	3/3500	201.40	0.52	175.90	0.23	253.71	2.11	221.07	2.35
20	4/3500	167.33	1.03	144.69	0.92	146.27	1.89	133.91	2.11
21	5/3500	100.93	1.78	83.95	1.44	120.43	3.92	105.20	2.76

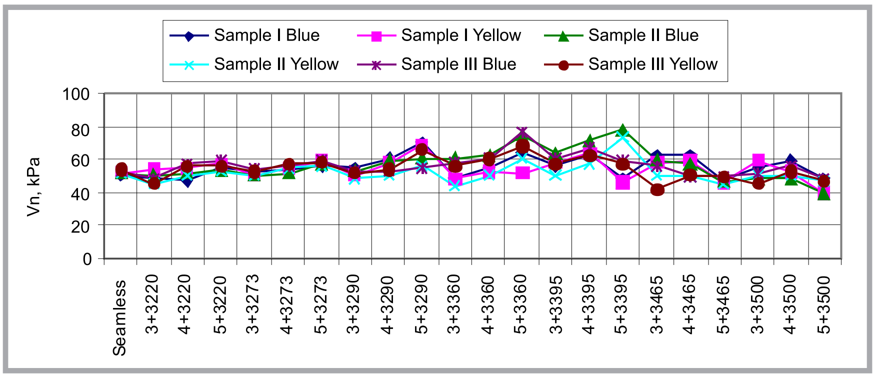

Figure 3. *Water impermeability of samples and colors; Vn – water impermeability in kPa, 3+3320 – time in s + power in W.*

In most cases the samples in blue have a higher breaking force and greater water impermeability than those in yellow.

The distance between the roller and paper in the unit for laminating knitted fabric affects the breaking force and elongation, water impermeability, mass per unit area and thickness of the sample.

Sample III with a smaller gap between the rollers and paper in the laminating unit had a higher occurrence of pressing the coating into the interspaces of the substrate, resulting in a stiffer but also stronger material.

According to the relationship between the values of the breaking forces and water impermeability, it can be concluded that there is no strong linear relationship; however, the values are distributed in a particular area of the coordinate system.

Conclusions

The following conclusions can be drawn on the basis of the tests conducted and the discussion:

The breaking force of the weld made by the high-frequency welding technique is affected by the type of material, which also depends on the composition and properties of PU coatings, as well as on the process parameters of high-frequency welding - power and duration of welding. Those conditions of welding power and duration were selected to produce seams of satisfactory appearance, specific strength and water impermeability.

By comparing the two additives Vithane S20 and Vithane ACR, it can be concluded that Vithane S20 mostly has a higher breaking force and greater water impermeability.

The pigments that are added to the PU paste have an impact on the quality of the welded seam in the case of VF welded pieces of clothing.

Editorial note

The results presented came from scientific projects (Anthropometric measurements and adaptation of the garment sizing system, coded as 117-1171879-1887, and Advanced technical textiles and processes, coded as 117-0000000-1376) conducted under the support of the Ministry of Science, Education and Sports of the Republic of Croatia.

Table 9. Water impermeability of samples I, II and III with a welded joint.

Sample	Conditions	Water impermeability, kPa											
	t (s) / S (W)	I sample				II sample				III sample			
		Blue		**Yellow**		Blue		Yellow		Blue		Yellow	
		x, kPa	CV, %	x, kPa	CV, %	x, kPa	CV, %	x, kPa	CV, %	x, kPa	CV, %	x, kPa	CV, %
1	3/3220	48.21	13.22	54.22	10.44	50.41	11.82	45.09	13.33	48.52	10.55	45.62	12.77
2	4/3220	47.31	11.76	55.17	13.81	51.71	14.77	50.27	12.09	56.63	10.36	55.44	10.82
3	5/3220	55.02	10.55	57.34	12.67	54.22	10.33	52.91	11.77	58.90	11.90	55.91	12.55
4	3/3273	52.82	12.77	50.58	10.82	50.19	14.61	50.91	14.77	53.89	10.35	52.30	10.62
5	4/3273	54.16	9.08	55.03	15.77	51.33	11.03	55.33	15.81	55.41	11.53	57.01	12.63
6	5/3273	55.55	13.51	58.71	14.71	56.47	9.02	56.04	13.41	59.27	9.33	58.03	10.77
7	3/3290	54.67	11.43	50.61	10.38	52.38	14.55	48.19	13.70	52.52	10.37	51.19	14.77
8	4/3290	60.44	10.99	58.33	14.05	58.66	12.55	50.06	10.33	53.03	8.82	53.44	11.09
9	5/3290	70.31	10.51	68.51	12.99	60.03	12.91	55.89	13.22	55.19	11.09	65.72	12.78
10	3/3360	48.32	13.81	48.88	13.46	60.43	13.29	44.32	16.30	58.23	11.32	55.92	12.77
11	4/3360	54.80	12.71	52.7	11.52	62.61	14.07	50.07	12.77	60.06	10.71	60.08	13.27
12	5/3360	63.23	10.33	52.00	15.09	74.02	10.22	60.47	12.71	75.88	11.09	67.33	10.03
13	3/3395	55.71	8.44	58.02	13.88	63.55	12.54	50.83	12.00	60.50	10.77	56.71	14.60
14	4/3395	62.15	9.21	62.92	12.93	71.09	13.29	56.91	12.99	66.82	12.24	62.88	15.32
15	5/3395	48.22	16.33	46.39	14.55	77.82	14.55	73.21	13.47	58.91	13.22	57.45	14.33
16	3/3465	62.55	13.09	58.11	14.55	58.81	11.99	50.63	10.71	55.92	13.67	42.40	12.30
17	4/3465	62.87	14.61	59.09	13.23	57.32	14.32	49.02	13.55	50.00	13.60	50.42	14.00
18	5/3465	47.82	14.23	45.88	15.41	46.11	12.20	45.66	15.29	49.01	14.30	49.22	15.88
19	3/3500	54.71	12.42	59.59	14.55	48.49	14.11	50.05	13.89	51.68	10.03	45.66	11.66
20	4/3500	58.71	13.22	52.43	13.47	48.00	13.20	51.00	12.30	55.78	12.87	52.31	14.55
21	5/3500	48.34	14.22	40.32	14.00	40.21	14.55	47.33	13.44	48.66	13.27	46.90	13.29

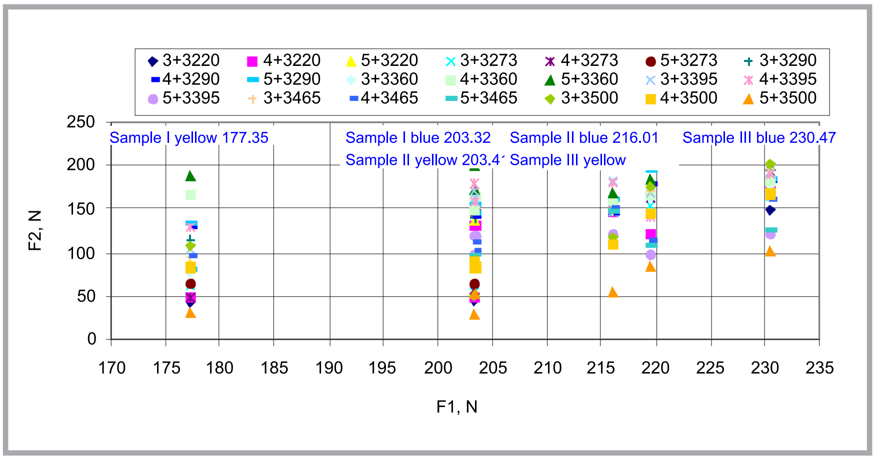

Figure 4. Relationship between breaking force without a seam and breaking forces with a seam; F1 – breaking force of seamless samples in N, F2 – breaking force with seamed samples in N.

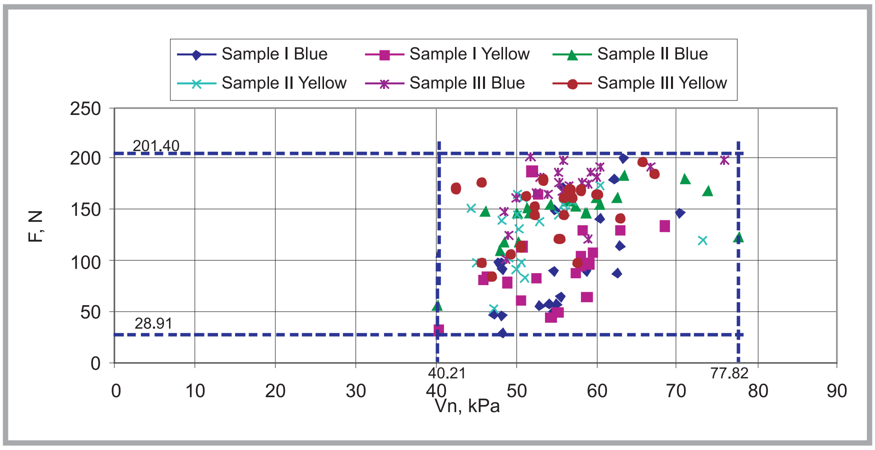

Figure 5. Relationship between the breaking forces and water impermeability for each samples and forces.

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