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INFLUENCE OF WELDING PHYSICAL CONDITIONS ON WATERPROOFING MEMBRANE WELD QUALITY

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Preliminary notes

The paper deals with the influence of factors on the welding of waterproofing membranes in order to achieve the technological process rationalization. The influence of factors (speed, temperature, and welding time) upon waterproofing membrane weld quality was assessed through an experiment. The most suitable factor combinations were determined with the aim to ensure the welds of the highest quality. Thus a tool for the less experienced welders was generated by means of which the period of an operator's training shall be reduced.

Keywords: *waterproofing membrane, welding*

Utjecaj fizikalnih uvjeta zavarivanja na kvalitetu zavarenog spoja vodonepropusne membrane

Prethodno priopćenje

Članak se bavi utjecajem čimbenika na zavarivanje vodonepropusnih membrana u cilju postizanja racionalizacije tehnološkog procesa. Utjecaj čimbenika (brzine, temperature i vremena zavarivanja) na kvalitetu zavara vodonepropusne membrane ocijenjen je eksperimentom. Utvrđene su najprikladnije kombinacije faktora s ciljem osiguranja zavara najviše kvalitete. Tako je za manje iskusne zavarivače razvijen alat pomoću kojega će razdoblje osposobljavanja zavarivača biti smanjeno.

Ključne riječi: *vodonepropusna membrana, zavarivanje*

1 Introduction

Nowadays, due to their numerous favourable properties, plastic materials replace other materials in many industries, especially packaging industry, therefore the generation of plastic waste is constantly increasing [1-13]. Remarkable growth of flat roof insulation commenced in the 1970s of the last century. A flat roof is a roof with a slope up to 15°. Initially the flat roofs were insulated using melting bituminous asphalt strips. Insulations were realized through a free flame in case of which an asphalt strip was preheated and adhered to a prepared roof base. Their drawback was in short durability. The welded PVC films were preceded by the adhered ones joined by adhesives [1], [7]. Due to unsatisfactory experience related to adhesives changing their properties after some time and occurrence of opening of joints the film strips began to be welded. At present the films are recommended to be merely welded [14, 15, 16]. Films are welded using automatic welding machines and manual hot air guns in contrast to bitumen being melted down manually by free flame. Material and work guarantee significantly differ. In case of bituminous strips the period ranges from approximately 2 to 3 years whereas film guarantee is minimally 10 years.

2 State of the art

Currently, according to the available data, both in Slovakia and the Czech Republic, to insulate roofs and basement complexes of large shopping centres in construction so as to prevent water, humidity and radon PVC films are used by diverse world producers including Fatra, Carbofol, Sika, Juta, Agru, Flagon. Trainings of PVC film welders lasting usually 1 week are held in Slovakia within the frame of material producers or suppliers. They are organized annually or every other year. It is a rather short period of time to train a welder for practice. Information is passed on within the scope of companies in the form of welders' skills being proved in practice. Nowadays no tabular values exist to weld PVC material. Producers provide solely rough temperature ranges in machine set-up according to welded film thickness. Roof insulation guarantee periods apply generally to 10 years. Insulation group normally consists of four to seven people two of whom are experienced welders capable of handling and setting optimal parameters to ensure welding by means of automatic welding machine or manual welding machines. The objective of my work is to model miscellaneous welding parameters and to detect tensile forces of individual samples. In this way I would like to establish a tool for the PVC film welders – a table containing the values the parameters of which ensure the most solid weld. Thus the welding work quality is assured to the utmost. Eventual claims concerning leakages of roofs and basement complexes are eliminated to the largest extent, as repairs are financially demanding. The claims lie in damaged insulation replacement, drying and renovation of destroyed interiors under insulated covering (wall drying, decoration, floor and furniture recovery, etc.). One of the most significant welding conditions is to provide both clean instruments of welding elements and welded areas, too. Active areas of hot bodies as well as tools and instruments and areas being joined are inevitable to be thoroughly cleaned. Usage of textile material for cleaning is unsuitable therefore many times paper not giving off fibres – toilet-paper is applicable - and pure cleaning agent-free water are used [4, 16, 17, 18, 19, 20]. Film thickness depending on type of use and material supplier may be selected in the range from 1,00 mm up to 2,00 mm. Roof utilization intended film is UV stable and reinforced by fibres preventing shrinking. In dependence on a producer material guarantee is minimally 10 years. Film strip width ranges from 1,2 to 2,0 metres. Recommended thickness in case of roof insulation is minimally 1,5 mm adhering to 10-

year guarantee period. To insulate basement complexes PVC films with thickness ranging from 1,2 to 2,0 metres are used. In general those are not UV stable. In covering beads the weld covering is to be of minimum 10 cm. Width of the weld must be 3 cm at least [1]. External ambient conditions influence both assembly period and savings of assembling companies. Under correct optimization of welding processes, observing qualitative and quantitative parameters, welding company can achieve significant savings. Air humidity measurement is to be monitored when welding. High concentration of water vapour results in a dew point formation. The dew point temperature changes depending on outside temperature and relative air humidity [15, 16]. Effects of external ambience and their countermeasures are given in Tab. 1.

Table 1 Conditions and effects for film welding and countermeasures

Environmental conditions	Impact on welding	Countermeasures
Rainfall	Faulty welds, it is not possible to weld	Build a protective tent to prevent water intrusion
High humidity Must not exceed 80 %	Condensate, particularly related to the low temperatures	Immediately prior to welding preheat welding zone and dry areas
Low temperatures (<5 °C)	Condensate formation, changed welding conditions of condensate	Preheat the welded area at 10÷15 °C. Use plant protective tent (if available)
High temperatures	Inadmissible dimensional changes, high thermal expansion	Adaptation conditions
Direct sunlight	Unequal thermal expansion, changes in dimensions and shapes	Protect by covering
Wind, Draught	Increased irregular thermal expansion, unequal and irregular welding temperature. Insufficient plastification welding zone. Impurities in weld area (soot dust)	Shading walls (tent)
Chimney effect in the pipes	Improper cooling, heating and welding tools for welding areas	Conclude non-welded ends of a pipe welding
Different temperatures of welded parts	Increased irregular thermal expansion. Uneven welding temperature. Inadequate and irregular plastification welding	Tempering material for a sufficiently long period prior to welding

3 Material and methods

During experiments the FATRAFOL brand PVC film of 1,5 mm thickness was used. Different welding speeds, temperature and amount of exhaust air were selected according to empirical practice of the operator. In order to investigate strength of welded joints of PVC material with dimension 25×170 mm were prepared according to experimental conditions listed in Tab. 2. Samples were welded by compact and handy welding machine Tarpon by Herz GmbH Company. All destructive tests were conducted on tensile test machine WPM Thuringer Industriewerk Rauenstein 2 kN. All experimental runs were performed on laboratory room with temperature 20 °C.

Table 2 Experimental conditions (3 factors, 1 block, 35 runs)

Runs	Temperature / °C	Speed / m/min	Air / %	Exfoliation (Peel Strength) / N
1	400	1,5	100	60
2	400	2,0	100	40
3	400	2,5	100	35
4	400	3,0	100	20
5	450	1,5	100	130
6	450	2,0	100	95
7	450	2,5	100	65
8	450	3,0	100	35
9	500	1,5	100	155
10	500	2,0	100	120
11	500	2,5	100	110
12	500	3,0	100	65
13	550	1,5	100	115
14	550	2,0	100	135
15	550	2,5	100	140
16	550	3,0	100	110
17	400	1,5	80	70
18	400	2,0	80	42
19	400	2,5	80	18
20	400	3,0	80	10
21	450	1,5	80	125
22	450	2,0	80	85
23	450	2,5	80	45
24	450	3,0	80	25
25	500	1,5	80	151
26	500	2,0	80	108
27	500	2,5	80	80
28	500	3,0	80	55
29	550	1,5	80	132
30	550	2,0	80	150
31	550	2,5	80	120
32	550	3,0	80	100
33	600	2,0	100	75
34	600	2,5	100	105
35	600	3,0	100	105

Destructive assembling tests – tensile tests and tests by a "peel test" are carried out prior to welding and in case of any change of climatic factors (humidity, temperature, wind, etc.) which might influence welding temperature itself. The cooled weld is tested through tearing the upper strip off the lower one. When achieving the continuous weld the welding machine set-up is satisfactory along the entire width. The strip with width of approximately 25 mm and length of 170 mm is to be cut off the randomly selected weld and used to check the weld quality by destructive method (Fig. 2). Film welding quality is high if the film gets torn out of the weld area during destructive test. Visual weld check – all welds are to be visually checked after completing the welding [1, 9, 18].

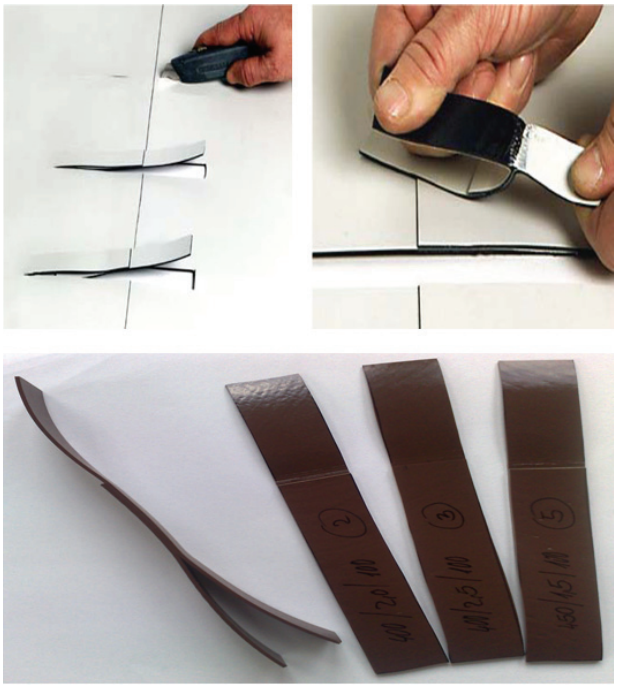

Figure 1 Samples

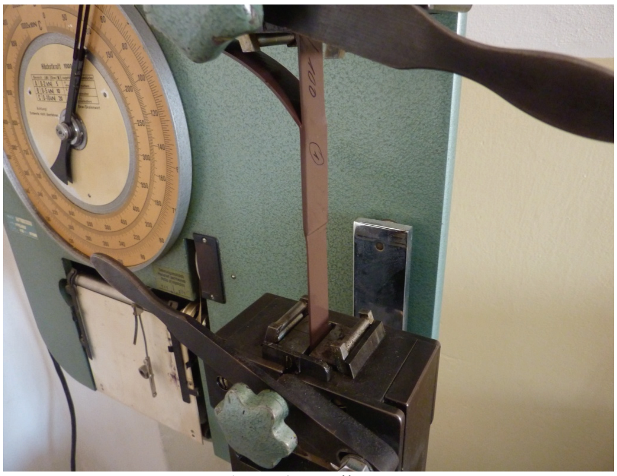

Figure 2 Tensile test

4 Results and discussion

In the tensile tests performed using a tensile machine no destruction in the welded joint of any sample was observed. Therefore we excluded the samples tested by this method out of further research. We focused on the peeling test results. Foreign literature uses also the term peel test [1]. In consideration of the measured values and after consultation with the welders of the Pastel Company we determined suitable samples showing peeling force from 100 N upwards. The results were used to construct a strength range curve of the most suitable values acquired in welding the experimental samples (Fig. 2). The results were analysed by Statistica 8, using the analysis of variance as appropriate to the experimental design used (Central Composite Experiments). The regression equation obtained after analysis of variance gives the level of average roughness as a function of independent variables listed in Tab. 1. Significant (Fig. 3) terms are included in the following equation 1:

$$Exf = 107{,}48 + 18{,}83 \cdot T - 8{,}97 \cdot T^2 - 27{,}75 \cdot S. \qquad (1)$$

The fit of the regression model is expressed by coefficient of determination $R^2 = 0{,}8979$ which was found to be for equation indicating that 89,79 % for the model of the variability in the response can be explained by derived Eq. (1). This shows that equation is suitable model for describing to the response of the exfoliation. The value of adjusted coefficient of determination *adj* = 0,8735 is high to advocate for a high significance of the regression Eq. (1).

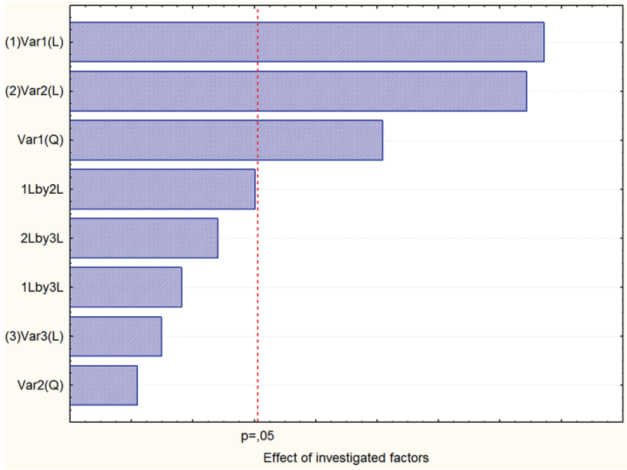

Figure 3 Pareto chart shows that temperature and welding speed as a controlable factor were found to be the most sufficient factors that affect the Exfoliation (N)

The significance of independent variables is interpreted in the Pareto chart of standardized effects for variable Exfoliation (N) (Fig. 3). The following Fig. 4 shows fitted surface of speed and temperature. To construct strength curves speed parameters of the welding machine TARPON by the HERZ Company were opted for the horizontal axis. The vertical axis shows peel force data detected in case of the tensile machine FM 1000. Strength range data were limited through welding parameters having been proved to be the optimal. In this case it was the temperature, the samples were welded at, and amount of additional hot air. Data displayed on the automatic welding machine being digitally set up to 100 % represent the value of 500 l/min of the air. Data 80 % represents the value of 400 l/min of the hot air. As to strength the samples with welding temperature range from 450 °C to 600 °C were the most suitable (Fig. 5). The samples welded at 450 °C possessed almost identical results with the amount of air reaching 100 % or 80 %. Welding at such temperature requires a short range of welding speed. Welding at the foregoing temperatures is recommended to the professional welders only. The strength curve shows rapid drop in strength of the welded joint even in case of slight speed increase of welding. As per welders´ experience such temperature parameters are advisable to be preset only if the ambient air temperature reaches over 28 °C.

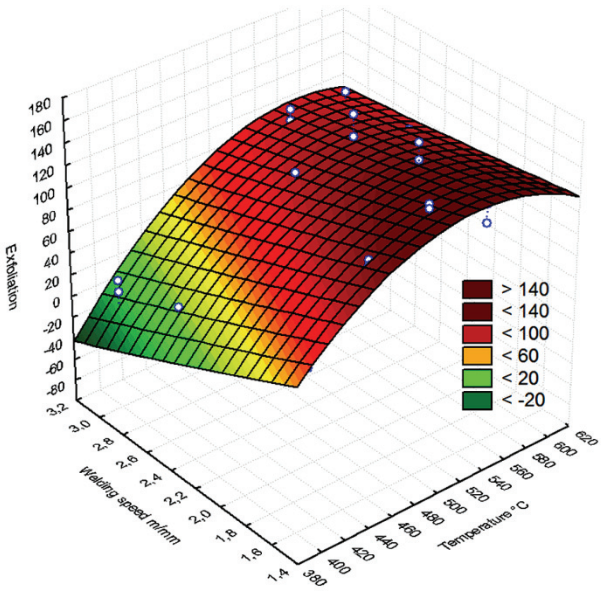

Figure 4 Fitted surface of welding speed and temperature. Three-dimensional surface plot showing predicted value (Exfoliation) as a function of tempreature and speed (Tab. 1)

A very interesting phenomenon occurred when the automatic welding temperature was increased to 600 °C. Strength of joints did not increase. Yet rather high film smoking at the point of the weld could be observed during welding. We assume that at these temperatures additional filling agents (additives) were being burnt on the welded film. This may be a cause of relatively low strength of the welds. Welding at these temperatures is recommended if the ambient temperature drops below 10 °C or under unfavourable wind conditions bringing about cooling of the welds. Such welding temperatures might be coped with by the professional welder only.

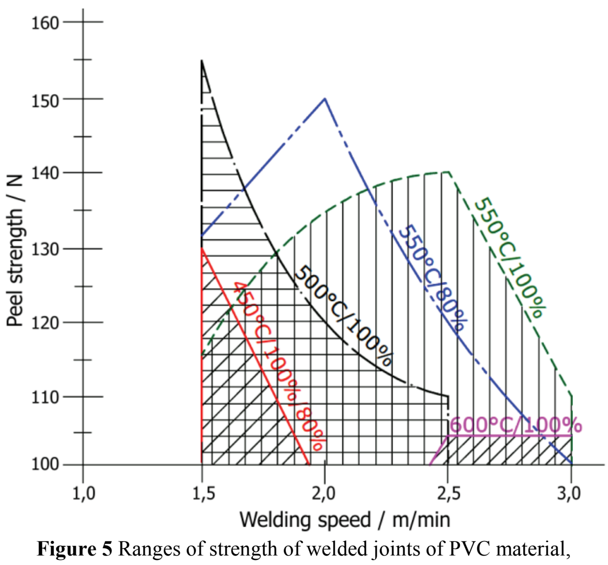

Figure 5 Ranges of strength of welded joints of PVC material, depending on temperature, amount of additional air and welding machine speed

Temperatures around 550 °C ensure optimal welding zone for even less experienced welders. Range of 100 % air is advisable in case of lower ambient temperatures from 5 °C to 20 °C and selection of range of 80 % air is recommended at ambient temperature ranging from 20 °C upwards. At these temperatures a relatively high possibility exists of welding speed selection and achievement of a good result in case of the welded joint. The measured results very clearly show welding zones with positively strong welded joint of high quality.

5 Conclusion and remarks

In this work, we focused on quality evaluation of the welding parameters of waterproofing membrane in order to achieve the highest quality of the welded joints. Evaluate were tensile parameters of welded samples according to experimental design following factors speed, temperature, and welding time were employed in this study. A design of experiments was used for investigation of significance employed factors. Temperature and welding speed as controllable factors were found to be the most sufficient factors that affect the parameter – Exfoliation. Derived regression equation predicts the behaviour of the quality parameter. It has a significant impact on economy and companies. We believe that the data obtained will serve as a credible figure for the current and future welders.

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