DOI: 10.1515/amm-2016-0276

P. IREK*,#, .J.SŁANIA*

MATERIAL FACTORS IN RELATION TO DEVELOPMENT TIME IN LIQUID-PENETRANT INSPECTION. PART 2. INVESTIGATION PROGRAMME AND PRELIMINARY TESTS

The paper is the continuation of the previous one entitled "Material factors in relation to development time in liquid-penetrant inspection. Part 1. Material factors" in which the material factors influencing essentially the development time in penetrant testing have been marked out. These are: type of material, surface roughness and imperfection width. In the paper it has been described how to prepare the factorial plan which will enable to test every factor with taking into account its different values. Moreover, it has been presented investigations on natural cracks, their width and roughness profile what will allow to assign suitable values of independent variables to the factorial plan. The purpose of the plan prepared in such a way will be the determination of the influence of the material kind , surface roughness and discontinuity width on the development time in penetrant testing.

Keywords: imperfection, defect, penetration testing, adhesion

1. Introduction

The paper is the continuation of the previous one entitled "Material factors in relation to development time in liquid-penetrant inspection. Part 1. Material factors" in which the material factors influencing essentially the development time in penetrant testing have been marked out. These are: type of material, surface roughness and imperfection width.

The aim of the present investigations is to determine the influence of the kind of material, surface roughness and the width of discontinuities on the time of development in penetrant testing.

The investigations are to answer the following questions:

- is there a relation being the function of material factors which determines the time of development?
- How far each material factor affects the development time?

It has been assumed the following aims of investigations:

- Cognitive aim: determination of the influence of particular material factors on the development time in penetrant testing,
- Utilitarian aim: development of technological recommendations for the choice of the development time in penetrant testing.

To this end, the investigations programme shown in the Fig.1 has been assumed.

On the basis of literature survey three kinds of materials have been chosen. These are the materials which are most often subjected to the penetrant testing while the times of development for these materials are different. The selected materials are:

- constructional steel,
- aluminium alloy,
- nickel.

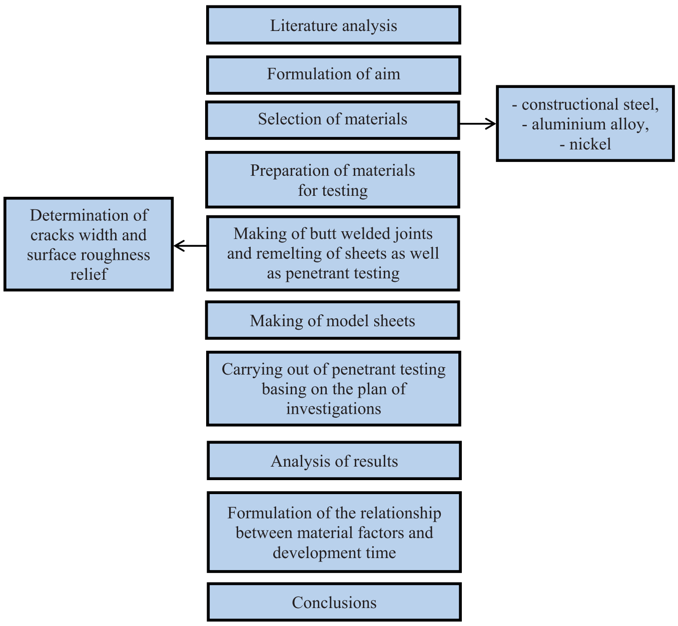


Fig. 1. Investigations programme

2. Investigations plan

For investigations purposes the plan of experiments has been assumed. It is recommended to design experiments with the use of so-called factor plans [1-4]. The factor plans are aimed at testing of interactions between particular

* INSTITUTE OF WELDING, POLAND, 16-18 BŁ. CZESŁAWA STR., 44-100 GLIWICE, POLAND
# Corresponding author: pawel.irek@is.gliwice.pl

factors affecting the development time. The experiment is carried out by making the succeeding tests. Their number is determined by the tested combination of factors which are independent variables. Together with the increase of the number of the factors to be tested and with the increase of levels (values) number assigned to particular factors the number of combinations to be tested becomes greater. The total number of combinations is calculated using the formula:

$$n_{cz}^{kcz} \quad (1)$$

where:

n_{cz} - number of levels assigned to a single factor

k_{cz} - number of factors

In planning of the experiment it was applied the STATISTICA program which contains the tools suitable for planning the factorial experiments and analyzing their results. The use of the module "Planning of experiments" entering into the composition of STATISTICA + QC package was made [5-7].

The first stage of the experiment was the selection of operational parameters, called also independent variables, which are of critical importance for the time of development. Basing oneself on the literature review and considering the initial laboratory experiments, it was chosen the following independent variables: kind of material, surface roughness and width of discontinuities. The experiment was planned with the application of randomized fractional factorial plan for the above mentioned variables to which three value levels had been assigned. The experiments plan provides for that each of variables will be tested on one of three levels: the lower, middle and upper one (Tabl.1).

TABLE 1

Factors subjected to testing and the levels assigned to them

Level of factor	**Process: time of development**		
	Factors subjected to testing		
Independent variables	Kind of material	Surface roughness	Discontinuity width
Lower level	x_1	y_1	z_1
Middle level	x_2	y_2	z_2
Upper level	x_3	y_3	z_3

In order to estimate the error resulting from the test procedure, each process was repeated three times. The factorial plan formed in this way is shown in Table 2.

TABLE 2

Factorial plan

Process no.	Matrix of experiment		
	Kind of material	Surface roughness	Discontinuity width
1	x_1	y_1	z_1
2	x_1	y_2	z_3
3	x_1	y_3	z_2
4	x_2	y_1	z_3
5	x_2	y_2	z_2
6	x_2	y_3	z_1
7	x_3	y_1	z_2
8	x_3	y_2	z_1
9	x_3	y_3	z_3

The materials for testing were selected on the basis of literature and initial tests. These are:

- constructional steel (S355J2C+N),
- aluminum alloy (AlSi1MgMn),
- nickel (Nickel 200).

TABLE 3

Analysis and mechanical properties of S355J2C+N steel

Chemical composition								
C	Mn	Si	P	S	Cr	Ni	V	Cu
0,2%	1,35%	0,184%	0,012%	0,006%	0,02%	0,01%	0,005%	0,002%
Mechanical properties								
Rm, MPa		Re, MPa				A, %		
612		497				24		

TABLE 4

Analysis and mechanical properties of AlSi1MgMn alloy

Chemical composition									
Mg	Si	Mn		Fe	Zn	Cu		Cr	Al
0,6-1,2%	0,7-1,3%	0,4-1,0%		<0,5%	<0,2%	<0,1%		<0,25%	The rest
Mechanical properties									
Rm, MPa		Re, MPa			A, %			HB	E, MPa
Guaranteed	Typical	Guaranteed	Typical		Guaranteed	Typical		Typical	
295	350	240	305		8	11		105	69000

TABLE 5

Analysis and mechanical properties of Nickel 200 [15]

Chemical composition							
Ni	Fe	C	Mn	Si	Cu	Mg	S
>99,2%	<0,4%	<0,1%	<0,3%	<0,1%	<0,25%	<0,05%	<0,005%
Mechanical properties							
Rm, MPa			Re, MPa			A, %	
462			148			47	

Constructional steel S355J2C+N is the alloy steel characterized by higher strength owing to the alloy additions (Nb, Ti, V) [8-12]. It is one of the most common constructional steels used in fabrication of welded products due to its strength, relatively low price and simplicity of welding. The chemical composition of this steel is shown in the Table 3. The high iron content allows to investigate the influence of this element on the development time in penetrant testing.

Al-Mg-Si alloys are successfully applied in industry for the manufacture of welded structures. These precipitation hardened alloys (group 6, in accordance with PN-EN 573-1:2006) are still widely investigated as for their weldability [13,14]. AlSi1MgMn alloy is susceptible to hot cracks what should enable to carry out penetrant testing in this material. According to the Table 4, the minimum aluminum content in the alloy to be tested should be 95,45% , while the maximum one – 98,30%. So high aluminum level will enable to investigate the aluminum influence on the development time in penetrant testing.

The selected nickel grade – Nickel 200 – is the most often used nickel grade for fabrication welded structures. It is plastic worked nickel characterized by good mechanical , electrical, heat and magnetostriction properties as well as by the resistance against corrosion media in the wide range. High fineness level, min. 99,2% (Table 5), will enable to investigate the influence of nickel on the development time in penetrant testing.

In order to assign the value levels to the other factors (independent variables), welded joints with cracks should be made. The joints should be made of every kind of material selected for testing. After completion of welded joints in S355J2C+N constructional steel, AlSi1MgMn aluminum alloy and Nickel 200, the width of cracks in them should be measured. The number of measurements should depend on the crack length and should enable to calculate their arithmetic mean. Having the results tabulated, it will be possible to assign the discontinuity width values on three levels, namely lower, middle and upper one in such a way that these values on three levels may comprise the span of the measurement results.

3. Testing of natural cracks

The first material subjected to testing was the AlSi1MgMn aluminum alloy. In order to determine the cracks width it was made three butt joints, namely two joints, 160x240x6 mm, and one 140x240x6 mm, in dimensions, (Fig.2) and four sheets with notches. The joints were TIG welded with the use of filler metal in the form of wire, 1,2 mm in dia. The consumable, AlMg4.5MnZr, was selected in accordance with recommendations given in PN-EN 1011-4:2002/A1:2005 [16]. The sheets with notches, however, 140x240x6 and 140x216x6 mm ones and two pieces, 44x76x3 mm, in dimensions, were made in similarity to the Houldcraft's test, colloquially named the "fish skeleton" test, which shows the material susceptibility to hot cracking. The sheets were weld penetrated by TIG method, as it is shown in Fig. 3.

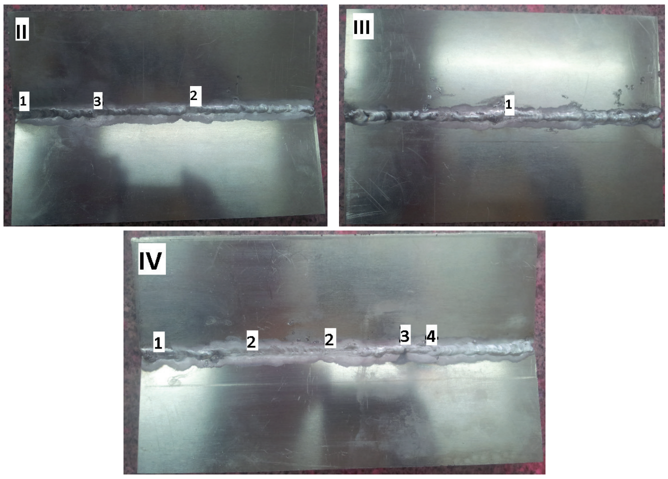


Fig. 2. Butt joints in AlSi1MgMn aluminum alloy. Roman numerals indicate the serial number of the joint while Arabian ones indicate the serial number of the crack in the joint

In accordance with expectation, in butt joints and TIG penetrated sheets, the cracks were formed, as it is shown in Figs. 3 and 4.

Macroscopic photos of cracks were made by means of Olympus SZX9 stereoscopic microscope (Fig.5) at magnification 4x and 28,5x (Fig.6). The cracks width was measured with the use of Auto CAD 2012 program on digital photos with visible cracks. The measurement accuracy was 4 μm. The number of measurements was different for each crack because the measurement of the crack width was made in 1 mm intervals. Therefore, the number of measurements for each crack was from several to over 100 ones, depending on its length. Denotations and cracks width in butt joints and remelt of sheets are made up in the Table 6.

Butt joints were made also in constructional steel and nickel and subjected to the same testing. Denotations and cracks width in butt joints and remelt sheets made in constructional steel and nickel are set together in the Tables 7 and 8.

The width of all measured cracks is within the interval of 4-1228 μm. Before breaking of test joints in the place of cracks formation (in order to test the roughness profile on the crack surface) it was made colour penetrant testing. To this end it was used a set of testing preparations, denoted according to the PN-EN ISO 3452-1 by the symbol of IICe-2, of the type „Diffu – Therm", of H. Klumpf Techn. Chemie KG D-45699 Herten manufacture (Fig. 7).

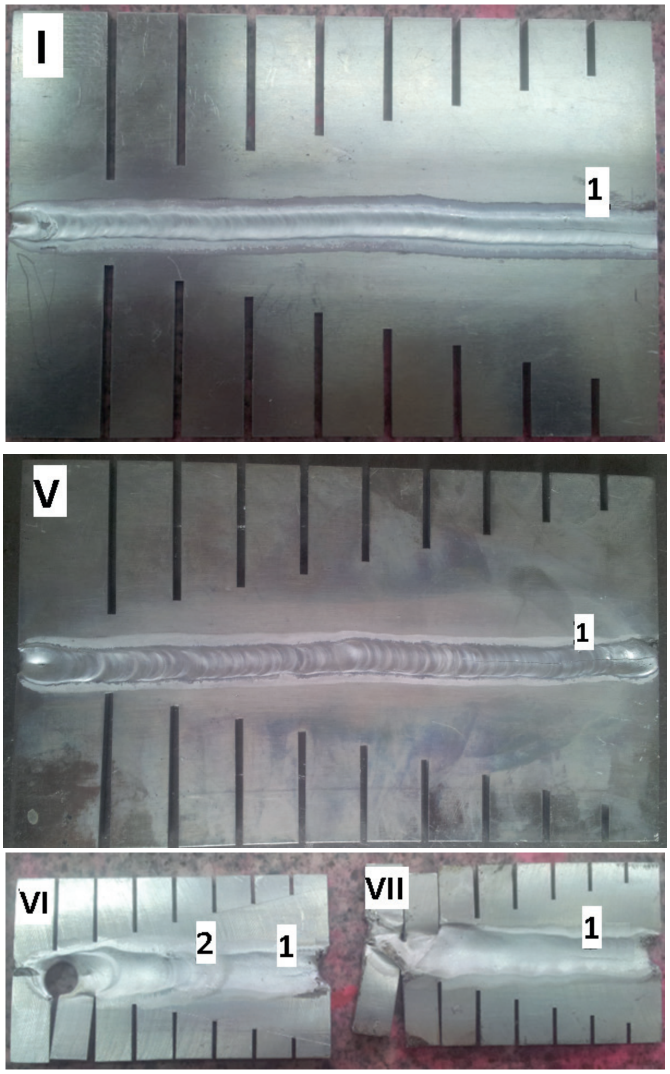


Fig. 3. Sheets with notches in similarity to the Houldcraft's test after TIG penetration (visible cracks). Roman numerals indicate the serial number of the joint while Arabian ones indicate the serial number of the crack in the joint

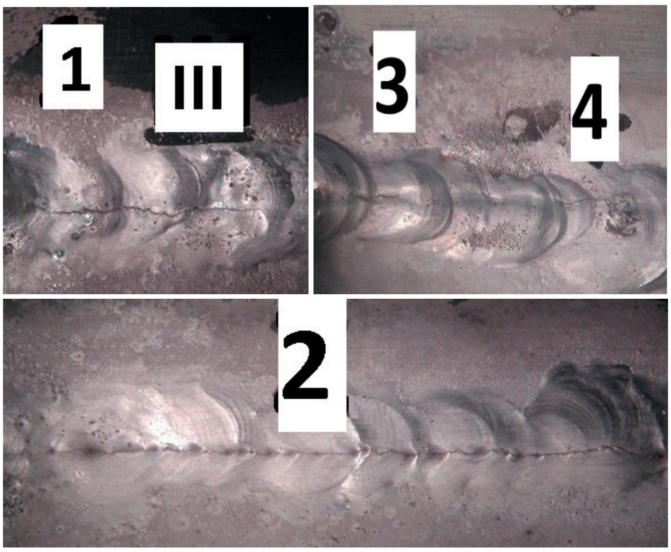
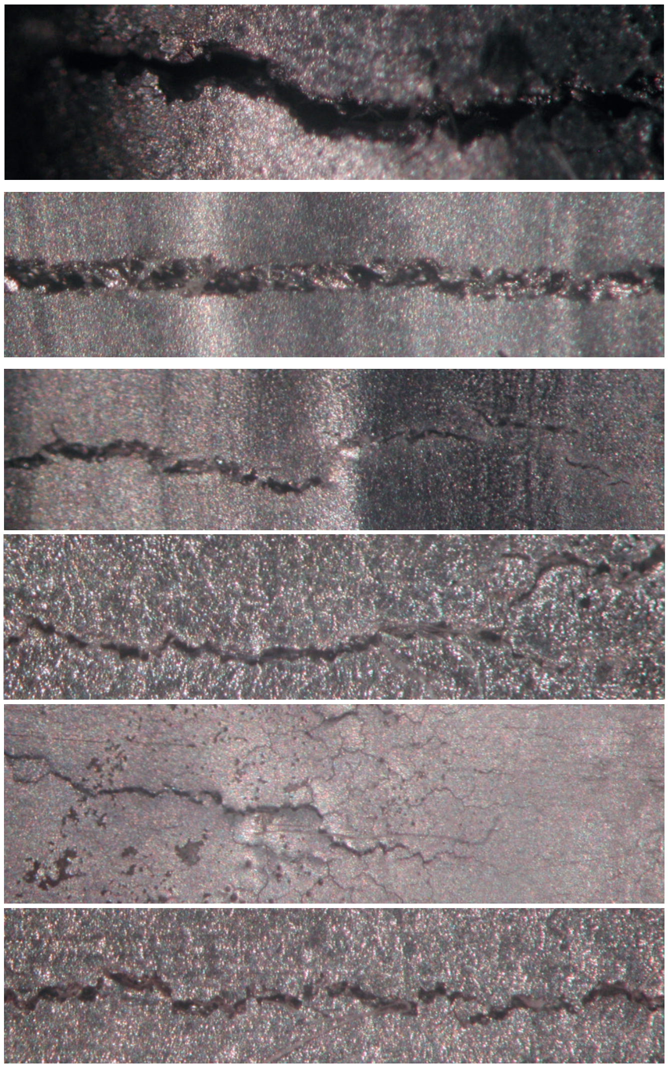


Fig. 4. View of exemplary cracks in butt joints made in aluminum alloy, magnified 4x. Roman numerals indicate the serial number of the joint while Arabian ones indicate the serial number of the crack in the joint

Fig. 5. Olympus SZX9 stereoscopic microscope



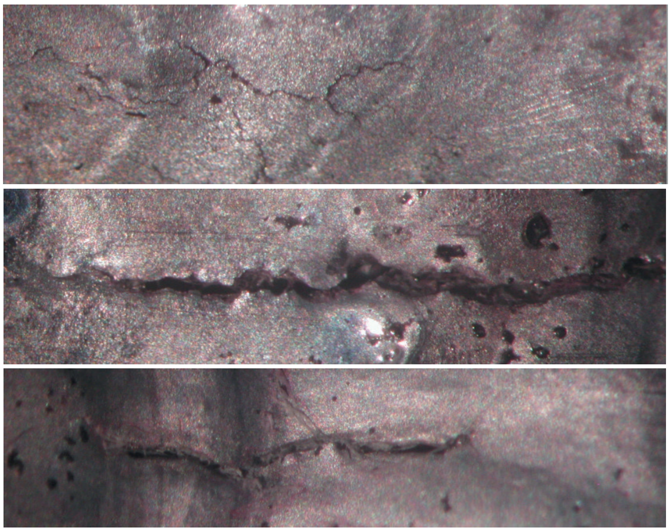


Fig. 6. Demonstration cracks in aluminium alloy butt joints; magnification 28,5x

TABLE 6

Denotations and cracks width in butt joints and remelt sheets made of AlSi1MgMn aluminium alloy

Number of joint/sheet	Number of crack	Crack width, μm
I	1	4÷260
II	1	28÷76
	2	8÷36
	3	4÷48
III	1	8÷236
IV	1	4÷24
	2	8÷112
	3	40÷92
	4	4÷72
V	1	12÷472
VI	1	16÷192
	2	4÷32
VII	1	14÷108

TABLE 7

Denotations and cracks width in butt joints made in Nickel 200

Number of joint	Number of crack	Crack width, μm
I	1	8÷612
I	2	28÷368
I	3	4÷340
II	1	4÷456
III	1	4÷204
IV	1	4÷272
	2	4÷48
	3	4÷248
	4	4÷104
V	1	4÷684
VI	1	4÷1228

TABLE 8

Denotations and cracks width in butt joints made in constructional steel

Number of joint	Number of crack	Crack width, μm
I	1	4÷344
I	2	4÷112
I	3	8÷108
I	4	20÷284
I	5	16÷104
II	1	12÷92
III	1	16÷1120
III	2	12÷276
III	3	8÷412
IV	1	4÷1144

The preparations were characterized by the following:

- penetrant – red colour, BDR-L type, series no.: 20 16, filling date: 04/2015,
- penetrant remover –BRE type, series no.: 22 17, filling date: 04/2015,
- developer–BEA type,: series no.: 23 17, filling date: 04/2015,
- guarantee period – 2 years,
- no chlorine and sulfur compounds in their chemical composition.

During tests the following equipment was used:

- luxmeter –LX 105 type of „LX Lutron" manufacture;
- thermometer/hygro-meter, model: MODEL 303,
- slide caliper, exact to 0,02 mm;
- workshop magnifying glass; magnification up to 4 x;
- non fraying woven fabric.

Fig. 7. Preparations set of the type „Diffu – Therm" used for penetrant testing of cracks

Penetrant testing of the cracks was carried out under the following conditions:

- temperature of the surface under testing – 22°C,
- surroundings humidity – 23%,
- penetration time – 15, 30, 60 minutes,
- penetration time – 15, 30, 60 minutes,
- luminance of the surface under testing – 584 lx,

- observation of indications – from the distance of 10-30 cm,
- observation angle – from 60 to 90°.

Penetrant testing was carried out with the use of colour penetration in accordance with PN-EN ISO 3452-1. Every crack was subjected to several tests while the test variables were the penetration time and the development time. The penetration time, according to PN-EN ISO 3452-1, should be from 5 to 60 minutes. The tests were carried out using the penetration time equal to 10, 30 and 60 minutes, whereas the measurements of indications were made in the following time points: 5, 10, 15, 20, 30, 40, 50, 60 minutes and so on until the indications development had been stopped (Table 9). In order to limit the number of measurements, only one indication coming from the longest crack was recorded for each sample. Each penetration test, at defined parameters, was made three times and the arithmetic mean of them was calculated.

The measurements made in the initial stage of the indications appearance were aimed at the more precise determination of the relation being the subject of the work as well as at the evaluation of the dynamics of their formation. The maximum time of indications development assumed in testing exceeded the recommendations of PN-EN ISO 3452-1, because in accordance with the standard specification it should be within the limits of 10 – 30 minutes. The time was extended in order to determine the appropriate development time, irrespective of the standard. The samples with developed indications are shown in Fig.8.

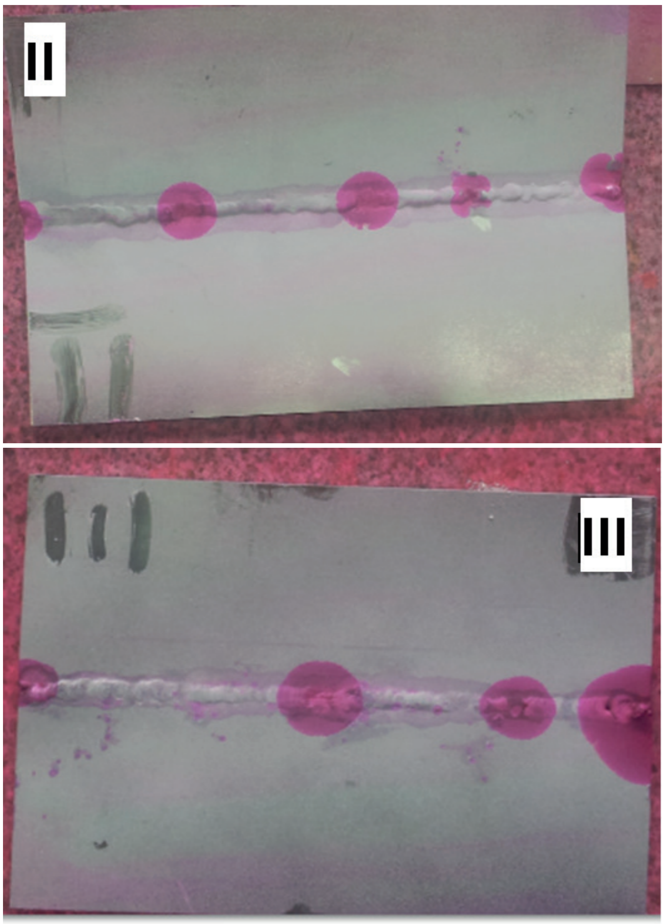


Fig. 8. View of selected samples of aluminium alloy with developed indications of cracks
Roman numerals mean the number of the joint

The penetrant testing of aluminium samples with cracks has shown that one of the purposes of this work has been achieved. The differences in development time found in testing of aluminium joints have not affected significantly the development time whereas they evidence rather the specific character of the testing process, itself. The penetrant testing process comprises a number of stages and each of them should be carried out with care for the details. Each carelessness in the testing process, usually unintentional, lowers the process sensitivity and brings about different final results. In this light it is easy to explain the disclosed inaccuracy, i. e. larger indications at shorter penetration time. It can be also observed that in most cases the value of indications increases dynamically up to about 15-20 minutes of development time. Later the increase of indications is very slow and most often it ends about 80th minute, what is shown in diagram (Fig.9). It suggests that in penetrant testing of joints in aluminium and its alloys this time can be considered as sufficient for detection of unacceptable external imperfections which are cracks, among the others. The sudden increase in indication length in case of the sample no. 4 is the result of mixing two single indications.

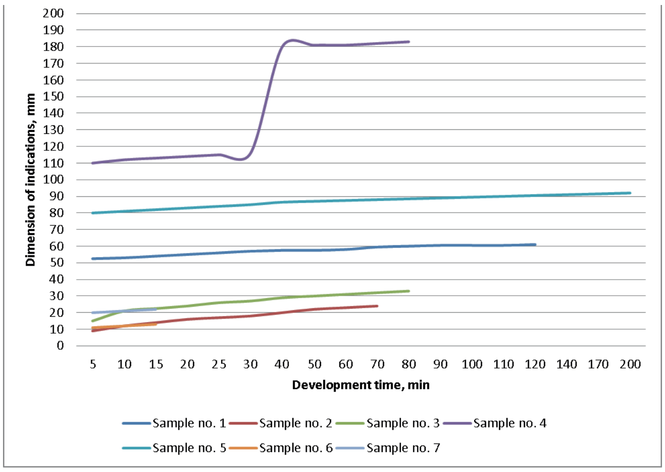


Fig. 9. Dimension of indications vs. development time for cracks in aluminium alloy

The same penetrant testing as in case of aluminium alloy joints has been carried out also for joints in nickel and in constructional steel (Figs. 10-11).

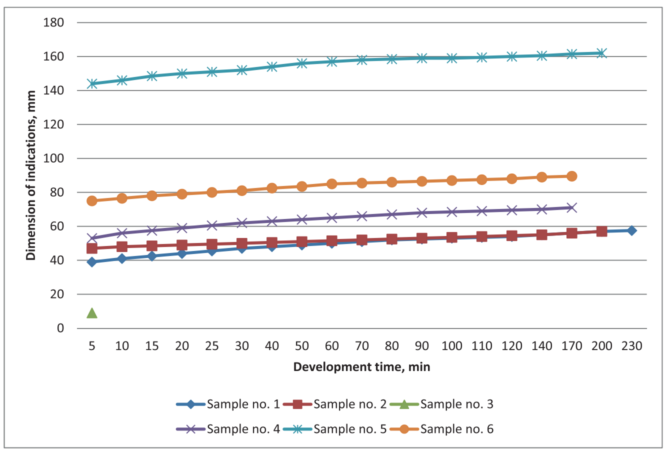


Fig. 10. Dimension of indications vs. development time for cracks in nickel

TABLE 9

Dimensions of indications coming from cracks in joints/sheets made of aluminium alloy
The penetrant was spread in such a way that the surface under testing was covered with the penetrant by the whole time

* - the joint under testing was covered with the penetrant only once.

Sample number - I																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	52	53	54	54	55	56	56,5	57	57	58,5	58,5	59	59	59	59,5	60	-	-	-	-
30	53	54	55	56	56,5	57	57	57,5	58	59	60	60	60,5	61	61,5	62	-	-	-	-
60	52,5	53	54	55	56	57	57,5	57,5	58	59,5	60	60,5	60,5	60,5	61	61	-	-	-	-
60*	53	54	55	56	56,5	57	57,5	58	-	-	-	-	-	-	-	-	-	-	-	-
Sample number - II																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	8	10	12	13	14,5	16	18	20	21	22	23	-	-	-	-	-	-	-	-	-
30	10	13	14,5	16	18	19	21	23	24,5	26	27	-	-	-	-	-	-	-	-	-
60	9	12	14	16	17	18	20	22	23	24	-	-	-	-	-	-	-	-	-	-
60*	10	12	13,5	14,5	15,5	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sample number - III																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	14	20	22	24	26	27,5	29	30	31	32	33	-	-	-	-	-	-	-	-	-
30	13	19	21	23	25	26,5	28	29	30	31	-	-	-	-	-	-	-	-	-	-
60	15	21	22,5	24	26	27	29	30	31	32	33	-	-	-	-	-	-	-	-	-
60*	14	19	22	23	23,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sample number - IV																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	111	113	115	116	117	118	186	187	188	189	190	-	-	-	-	-	-	-	-	-
30	111	112	114	115	116	117	184	185	186	186	187	-	-	-	-	-	-	-	-	-
60	110	112	113	114	115	116	180	181	181	182	183	-	-	-	-	-	-	-	-	-
60*	110	112	113	114	114,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sample number - V																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	83	83,5	84	85	85,5	86	87	88	88	88,5	89	90,5	91	91	91,5	92	92,5	93	-	-
30	84	84,5	85	85	86	86,5	87,5	88	88,5	89	89,5	90	90,5	91	91,5	92	92,5	93	-	-
60	80	81	82	83	84	85	86,5	87	87,5	88	88,5	89	89,5	90	90,5	91	91,5	92	-	-
60*	82	83	84	84,5	85	85,5	86	-	-	-	-	-	-	-	-	-	-	-	-	-
Sample number - VI																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	9	10	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	13	14	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	11	12	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60*	12	13	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sample number - VII																				
Time of penetration, min	Time of development, min																			
	5	10	15	20	25	30	40	50	60	70	80	90	100	110	120	140	170	200	230	260
10	21	22	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	20	21	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	20	21	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60*	21	22	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: The largest dimensions of indications, in millimeters, are given.

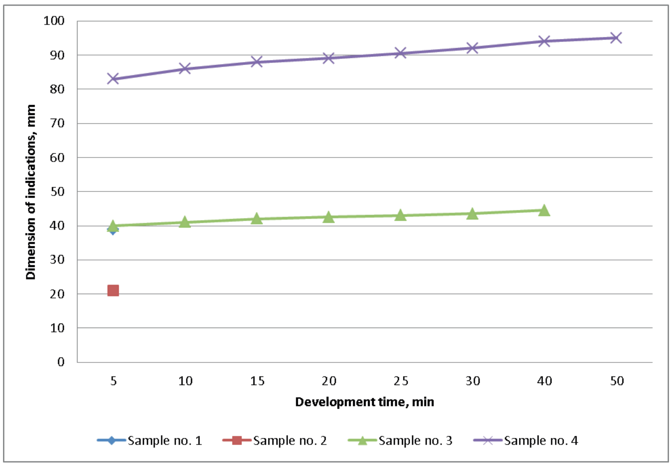


Fig.11. . Dimension of indications vs. development time for cracks in constructional steel

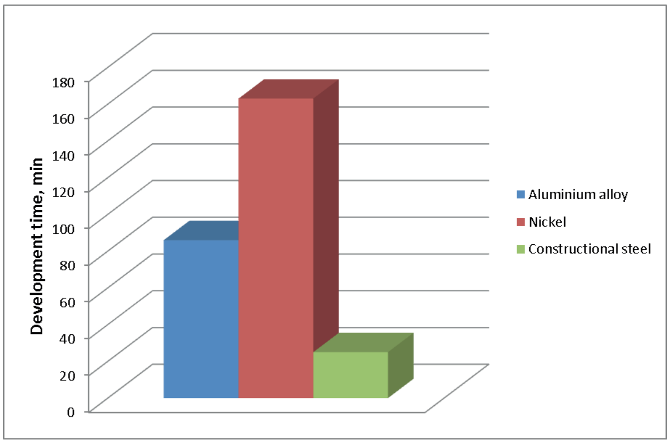


Fig.12. Average development times for tested materials

In case of nickel the longest penetration time was prolonged from 60 to 120 minutes on the basis of literature data and earlier experiments.

The differences in penetration time found in case of nickel joints have shown that at longer penetration time (120 minutes) the indications are larger. It can suggest the necessity of prolongation both the penetration and development time for this material. . It can be also observed that in most cases the dimension of indications increases dynamically up to about 15-20 minutes of the development time. Then the increase of indications is slow and most often it ends after about 170 minutes (Fig.10), i. e. two times later than in case of aluminium alloys.

The penetrant testing of constructional steel samples containing cracks has shown that the penetration time does not influence significantly the indication values. The development time for constructional steels is considerably shorter than that for aluminium alloy or nickel and it can be 60 minutes (Fig. 11).

The average development times for various materials are compared in the form of diagram in the Fig. 12. Significant differences in development time for individual materials are visible. In case of nickel the development time is about twice as long as that for aluminium alloy and five times longer than that for constructional steel.

The next stage of testing was the measurement of the cracks surface roughness. In order to determine the roughness profile on the cracks surface, the sheets and butt joints were broken in the place of cracks (Fig.13).

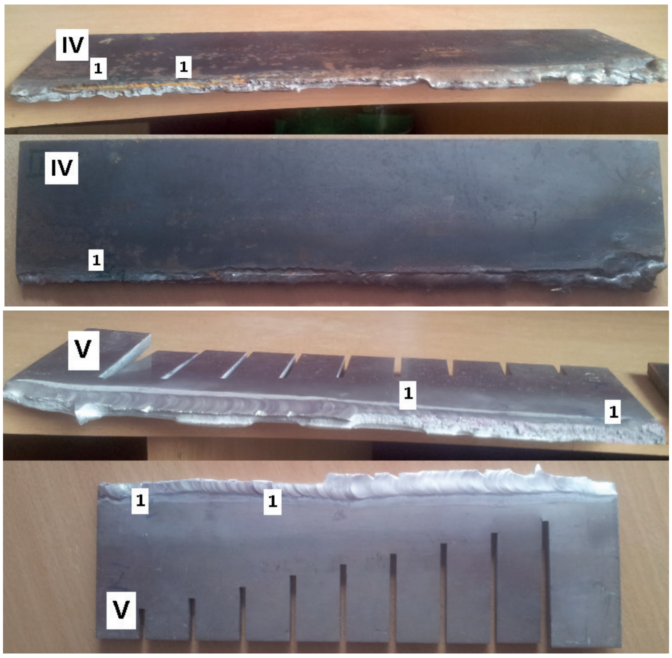


Fig. 13. Selected butt joints after breaking in the place of cracks. In the upper portion of the photo the part of butt joint in constructional steel is visible; in the lower – that of aluminium alloy. The Roman numerals indicate the serial number of the joint while the Arabian ones – the serial number of the crack in the joint

It was completed the stand for testing of roughness profile, in which the Turbo Datawin-NT computer program is integrated with the Hommel tester T1000 contact profile-meter (Fig.14). This measuring system enables to analyze dimensionally and statistically the microgeometrical parameters in the complex way as well as to visualize the stereometric structure of the surface under measurement.

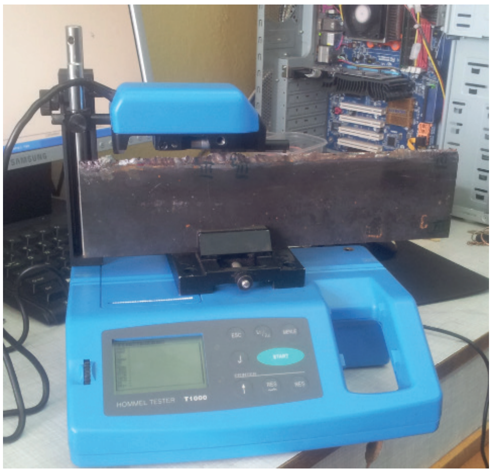


Fig. 14. Hommel tester T1000 contact profile-meter.

The waviness of the surface the roughness of which was to be measured created the difficulty. Therefore the device made two measurements. The first of them was the measurement of the surface profile while the second one was the roughness profile measurement (Fig. 15).

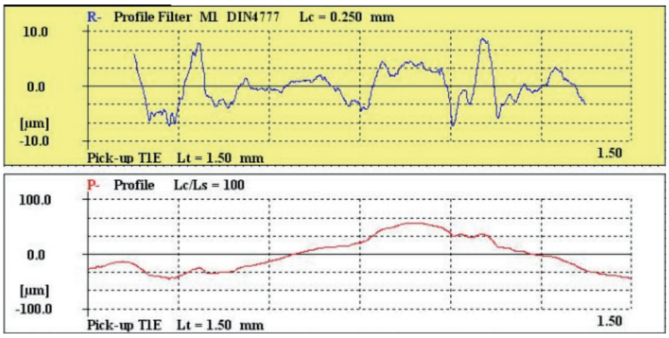


Fig.15. *Top* – Measurement of surface roughness; *Bottom* – Measurement of the profile

After approximation of the values resulting from the surface profile measurement the program converts them to the roughness profile. Additionally, during the measurement the visualization of the stereometric structure of the surface is shown on the device screen (Fig. 16).

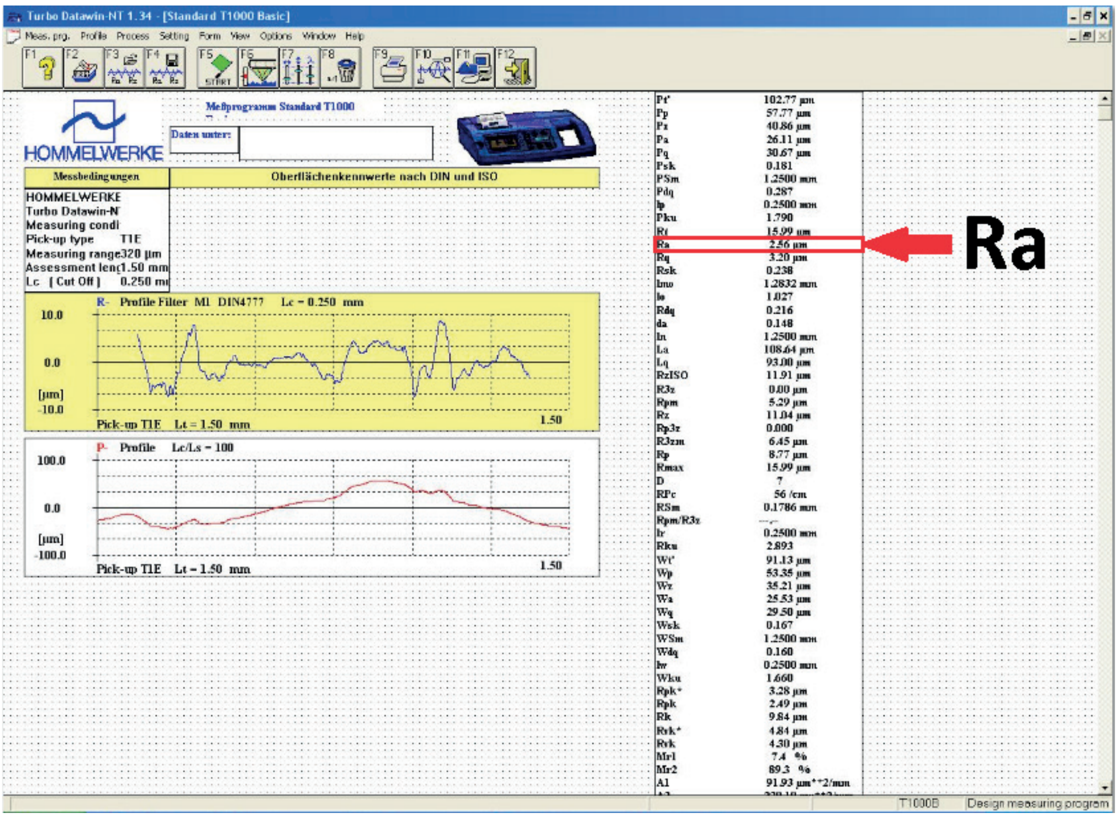


Fig. 17. Window of the Turbo Datawin-NT program. The parameter Ra, which will be analyzed in this paper is marked by red colour

TABLE 10

Crack surface roughness for test materials

CONSTRUCTIONAL STEEL			ALUMINIUM ALLOY			NICKEL		
Sheet/ Joint	Crack	Roughness Ra, µm	Sheet/ joint	Crack	Roughness Ra, µm	Sheet/ joint	Crack	Roughness Ra, µm
I	1	6,63	I	1	13,24	I	1	3,98
I	2	7,51	II	1	5,23	I	2	4,57
I	3	3,70		2	4,65	I	3	5,15
I	4	6,29		3	2,05	II	1	2,41
I	5	5,17	III	1	4,08	III	1	2,61
II	1	7,32	IV	1	2,01	IV	1	7,40
III	1	3,46		2	6,25		2	1,39
III	2	4,89		3	5,78		3	2,56
III	3	6,47		4	3,28		4	3,40
IV	1	5,66	V	1	9,14	V	1	1,66
			VI	1	5,59	VI	1	4,00
				2	8,37			
			VII	1	6,37			

NOTE: The Roman numerals indicate the serial number of the joint while the Arabian ones – the serial number of the crack in the joint.

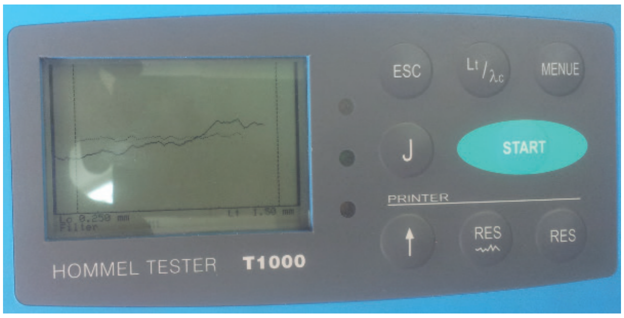


Fig.16. Visualization of the stereometric structure of the surface during the measurement

The program integrated with the profile-meter gives a lot of data on the surface under measurement (Fig.17). One of these parameters, namely Ra, i.e. the mean arithmetical deviation of the profile from the middle line will be given in this paper.

The roughness profile was measured for each crack in three places, next the result was averaged (Table 10). Some cracks failed to be measured because of the shape of the joint surface after breaking.

The surface roughness was measured according to the PN-EN ISO 4288:2011E specifications. The length of the elementary segment, l_r , was 0,8 or 2,5 mm while that of measuring segment, l_t , 4,8 and 15 mm, respectively. The values of elementary and measuring segments depend on the roughness range expected on the surface under measurement.

The crack surface roughness is within the range of 1,39 ÷ 13,24. It can be noticed that the crack surface roughness in constructional steel oscillates near to the same level and is within the range of 3,70 – 7,51. The largest range of the crack surface roughness can be observed for the aluminium alloy; it is 2,01 ÷ 13,24. However the crack surface roughness in the test grade of nickel was characterized by the smallest values of roughness which were included within the range of 1,39 ÷ 7,40.

4. Summary

The factorial plan prepared in the above mentioned way, considering three levels of each of factors (independent variables) and their impact on the development time (dependent variable), allows to make the statistical analysis. This, in turn, enables to approximate the interaction of the process operational variables on the basis of linear or quadratic models.

It permits to increase the reliability of estimation and to evaluate the interactions between independent variables.

The measured values of crack width and roughness profiles will enable to classify the suitable values on particular levels of independent variables.

The result of investigations should be the formulation of the relationship of the development time vs. particular factors. The relationship should determine how far the individual factor (independent variable) influences the development time (dependent variable). As it was mentioned before, there is lack of such information in the science-technical literature accessible nowadays.

REFERENCES:

[1] FDA, Pharmaceutical CGMPs For the 21st Century – A Risk-Based Approach, Final Report, 2004.

[2] FDA, Guidance for Industry PAT – A Framework for Innovative Pharmaceutical Development, Manufacturing and Quality Assurance, 2004.

[3] ICH, Q8 – Pharmaceutical Development, 2005.

[4] Ch. D. Hendrix, What every technologist should know about experimental design, CHEMTECH, March, 1979.

[5] W. Tarasiuk, B. Szczucka-Lasota, J. Piwnik, W. Majewski:, Tribological Properties of Super Field Weld with Micro-Jet Process. Advanced Materials Research **1036,** 452-457 (2014).

[6] R. Burdzik, Ł. Konieczny , Application of vibroacoustic methods for monitoring and control of comfort and safety of passenger cars. Solid State Phenomena **210**, 20-25. (2014).

[1] Ł. Konieczny, R. Burdzik,., B. Łazarz, Application of the vibration test in the evaluation of the technical condition of shock absorbers built into the vehicle. Journal of Vibroengineering **15,**, 4, 2042-2048 (2013).

[1] T. Węgrzyn, The Influence of Nickel and Nitrogen on Impact Toughness Properties of Low Alloy Basic Electrode Steel Deposits. Conference of International Society of Offshore and Polar Engineers ISOPE´2001, Stavanger, Norway 2001, Copyright by International Society of Offshore and Polar Engineers **4,**, 282-285, USA 2001,

[1] T. Węgrzyn, The Classification of Metal Weld Deposits in Terms of the Amount of Nitrogen. Conference of International Society of Offshore and Polar Engineers ISOPE´2000, Seattle, USA 2000, Copyright by International Society of Offshore and Polar Engineers **4** , Cupertino – California –130-134, USA 2000.

[2] A. Lisiecki, Diode laser welding of high yield steel. Proceedings of SPIE, Laser Technology, Applications of Lasers 8703, 22 (2012).

[3] A. Lisiecki, Welding of titanium alloy by Disk laser. Proceedings of SPIE, Laser Technology, Applications of Lasers, 87030 (2013).

[4] T. Węgrzyn, J. Piwnik, R. Wieszała, D. Hadryś: Control over the steel welding structure parameters by micro-jet cooling, Archives of Metallurgy and Materials **57**, 3, 679-685 (2012).

[5] L. Kolarik, K. Kovanda, M. Valova, P. Vondrous, J. Dunkovsky, Weldability test of precipitation hardenable aluminium alloy EN AW 6082 T6", Czech Technical University, Prague 2011.

[6] Norma PN-EN 573-1:2006: Aluminium i stopy aluminium. Skład chemiczny i rodzaje wyrobów przerobionych plastycznie. Część 1: System oznaczeń numerycznych. (PN-EN 573-1:2006 Standard: Aluminium and its alloys. Chemical composition and types of plastically worked products. Part 1: Numerical denotations system.)

[7] http://www.thyssenkrupp-vdm.com/fileadmin/Downloads/Datenblaetter/de/Nickel_99_2_d.pdf

[8] Norma PN-EN 1011-4:2002/A1:2005: Spawanie. Wytyczne dotyczące spawania metali. Część 4: Spawanie łukowe aluminium i stopów aluminium. (PN-EN 1011-4:2002/A1:2005 Standard: Welding. Guidelines for welding of metals. Part 4: Arc welding of aluminium and its alloys.