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Analysis of Indications in Penetrant Tests of Welded Joints

Abstract: The article presents the analysis of indications detected in penetration tests of welded joints. The analysis was based on tests of butt welded joints made of aluminium and steel. The study involved various durations of the phase of penetration and that of development. A detailed assessment of indication sizes was based on a registered continuous test.

Keywords: non-destructive tests, penetrant tests, welded joints, welding imperfections

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Introduction

Welded structures require a thorough qualitative assessment based on numerous destructive and non-destructive tests. Because of their non-invasive nature, priority is given to non-destructive tests, the aim of which is to verify the obtainment of a quality level assumed in a related design and ensuring the safe operation of welded products [1, 2]. In the first instance, the inspection includes surface tests, including visual tests (VT), penetrant tests (PT) and magnetic particle tests (MT) as well as volumetric tests, i.e. radiographic tests (RT) and ultrasonic tests (UT). Scopes of inspections related to surface and volumetric tests are based on related standards, design assumptions and performance requirements [2, 3]. Individual tests are performed in accordance with requirements of related standards, where a given testing method must be applicable within a required sensitivity range [4–6]. Visual tests, considered as basic tests, are performed on the basis of detailed conditions specified in the PN-EN ISO 17637 standard. In relation to joints made of steel, the assessment of welding imperfections (if any) is based on the PN-EN ISO 5817 standard. In terms of joints made of aluminium, the assessment of welding imperfections is based on the PN-EN ISO 10042 standard [7–9]. Penetrant tests are performed in accordance with the PN-EN ISO 3452-1 standard, whereas the assessment of indications in based on PN-EN ISO 23277 [10, 11].

The study presents penetrant tests of joints welded under various conditions. The penetrant tests were performed to detect indications, which, afterwards, were subjected to assessment and detailed comparative analysis. The test results should provide important information concerning the welded joints.

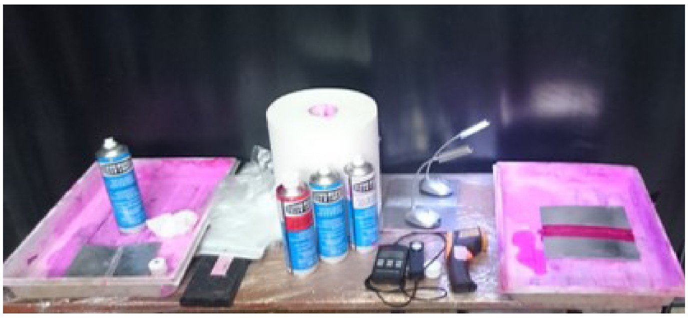

Fig. 1. Test rig

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Test rig

The penetrant tests of welded joints were performed using a dedicated test rig presented in Figure 1.

The test rig was equipped with two developing trays, for the cleaning of test specimens and for the performance of test-related operations. In addition, the test rig was equipped with:

- substances used in penetrant tests, i.e. dye penetrant BDR-L, developer BEA and cleaner BRE-S in accordance with system 3452-2-IICe-2, designated by the producer (DIFFUTHERM),
- Mavolux 5632L luxmeter for illumination measurements,
- DT8530 pyrometer for temperature measurements,
- image-recording camera,
- reference standard no. 2,
- cleaning agents,
- additional local lighting.

To provide appropriate working conditions, the test rig was also provided with an efficient exhaust system.

Subject of tests

The tests involved the making of two butt joints containing simulated discontinuities of linear and non-linear nature. The first test joint (4 mm ×170 mm × 200 mm) was made of aluminium sheets using the MIG welding method, whereas the second test joint (4 mm × 300 mm ×250 mm) was made of steel sheets using the MAG welding method. Both test joints are presented in Figures 2a and b.

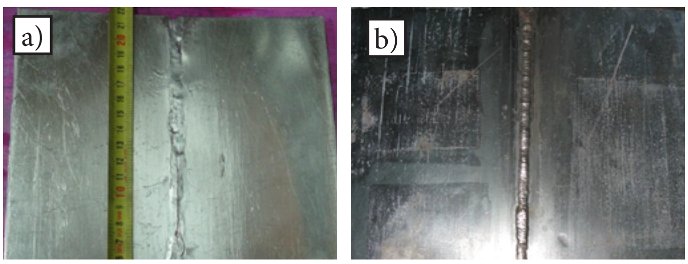

Fig. 2. Test joints used in the penetrant tests: a) aluminium joints, b) steel joints

Visual tests of welded joint

The primary tests of the butt welded joints were preceded by the performance of basic visual tests. The visual tests of the welded joints were performed from the face side and included the weld, HAZ and the area of the adjacent base material. The visual tests were performed in accordance with the requirements of the PN-EN ISO 17637 standard, whereas the assessment was based on the PN-EN ISO 5817 and PN-EN ISO 10042 standards [7–9]. The visual tests of the welded joint made of aluminium, i.e. specimen no. 1 (Fig. 2a) revealed the presence of two cracks having a length of 12 cm and 60 mm respectively. Because of the foregoing, the joint was qualified as representing quality level D in accordance with PN-EN ISO 10042. In turn, the joint made of steel, i.e. specimen no. 2 (Fig. 2b) did not contain welding imperfections. As a result, the joint was qualified as representing quality level B in accordance with PN-EN ISO 5817.

Penetrant tests of welded joints

Penetrant tests of the welded joints (specimens nos. 1 and 2) were performed using a test rig presented in Fig. 1 and the dye penetrant testing technique. The tests were performed in accordance with the requirements of the PN-EN ISO 3452-1 standard [10]. Before the tests, reference specimen no. 2 was verified for the usability of selected measures in accordance with adopted system 3452-2-IICe-2. The penetrant tests involving specimens nos. 1 and 2 were performed twice in relation to each specimen, changing times of penetration. Penetration times used in the tests amounted to 10 minutes and 20 minutes. In turn, the time of development adopted in the tests was constant in all of the tests and amounted to 30 minutes. The tests were performed at an ambient temperature of 210°C and illumination restricted within the range of 520 Lx to 560 Lx. To obtain the highest possible amount of data, the course of individual tests was monitored using a camera. To provide the appropriate scaling of images being recorded and enable the precise assessment of sizes of indications, a straightedge was placed on an element subjected to a test.

Exemplary series of images of indications revealed in specimen no. 1 after a penetration time of 20 minutes and development times of 1, 10, 20 and 30 minutes respectively are presented in Figure 3.

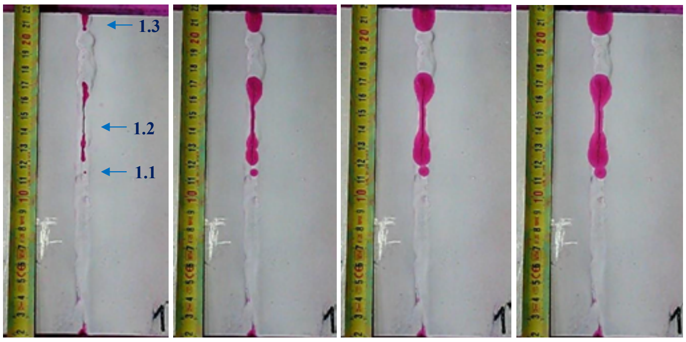

Fig. 3. Indications in specimen no. 2 after a penetration time of 20 minutes and development times of 1, 10, 20 and 30 minutes

The test of specimen no. 1 revealed the presence of actual indications of the following initial characteristics:

1. non-linear in relation to x = 95 mm,
2. linear in relation to x = 102 mm,
3. linear in relation to x = 187 mm.

The indications presented in Figure 3 are designated as 1.1, 1.2 and 1.3.

In relation to x = 0 mm, the edge of the specimen contained an apparent indication resulting from the incompletely cleaned lower edge of the specimen.

The test of specimen no. 2 revealed the presence of two actual indications of the initial linear characteristic, located in the weld axis and having coordinates x = 20 mm and x = 45 mm. Specimen no. 2 after various development times is presented in Figure 4. The identified actual indications presented in Figure 4 are designated as 2.1 and 2.2.

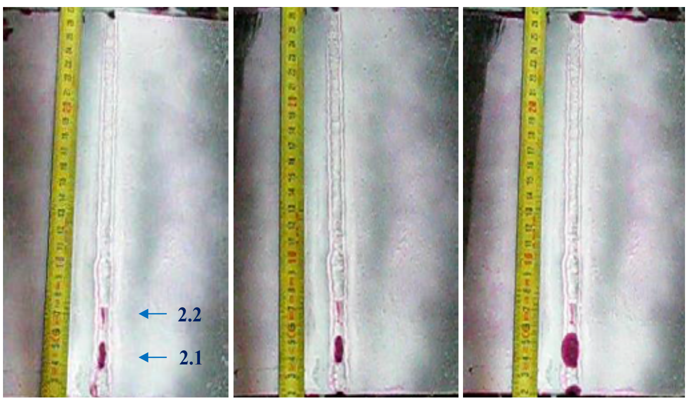

Fig. 4. Indications in specimen no. 2 after a penetration time of 20 minutes and various development times

In relation to x = 0 mm and x = 247, both edges of the specimen contained apparent indications resulting from the incompletely cleaned lower edge of the specimen.

Analysis of test results

The penetrant tests of the welded joints involving the continuous monitoring of the indications identified in specimens nos. 1 and 2 enabled the detailed description of changes in dimensions. Table 1 presents the sizes of indications nos. 1.1, 1.2 and 1.3 in relation to specimen no. 1 (made of aluminium), a penetration time of 10 minutes and that of 20 minutes as well as various development times.

The results in Table 1 are specified in accordance with indication characteristics. In relation to non-linear indications, the adopted dimension was d1, i.e. the diameter measured along the weld axis and d2, i.e. the diameter measured perpendicularly to the weld axis. In relation to linear indications, the length of an indication was identified as dimension l, whereas the greatest width of a given indication was identified as dimension b.

Table 1. Sizes of indications nos. 1.1, 1.2 and 1.3 in the aluminium specimen in relation to penetration times of 10 minutes and 20 minutes and various development times

Indication no.	Penetration time [min]	Indication size [mm]	Development time[min]					
			1	5	10	15	20	25
1.1	10	d_1	-	4.5	5.2	5.5	5.6	6.1
		d_2	-	5.0	5.5	6.0	6.1	6.4
	20	d_1	1.6	3.2	5.3	5.7	6.0	6.6
		d_2	1.6	3.2	5.5	6.0	6.6	7.4
1.2	10	l	10	52	59	60	61	62
		b	1.2	7.0	9.0	10.5	11.2	12.5
	20	l	50.3	51.6	61.3	61.5	62.0	63.0
		b	4.0	7.7	11.0	12.2	13.3	13.7
1.3	10	d_1	6.5	13.0	14.4	14.8	15.0	15.3
		d_2	4.0	9.0	9.7	10.8	11.4	11.6
	20	d_1	12.0	13.0	13.4	14.2	15.0	15.4
		d_2	5.0	10.1	11.5	13.7	15.6	17.0

The data presented in Table 1 were used to develop diagrams presenting dependences of indication sizes in the function of time in relation to a penetration time of 10 minutes and that of 20 minutes. Figures 5, 6 and 7 present dependences in relation to indication 1.1, 1.2 and 1.3 respectively.

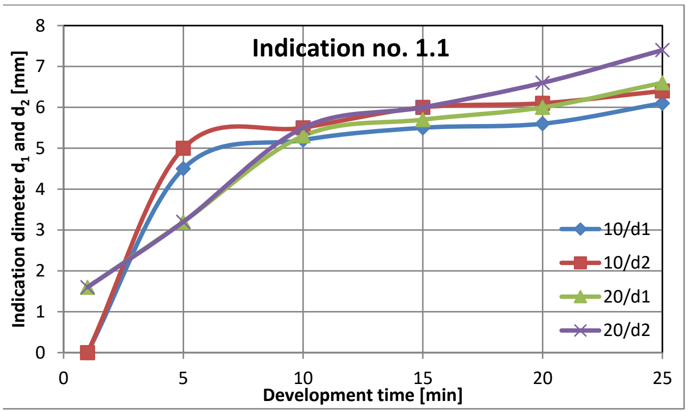

Fig. 5. Size of indication no. 1.1 in the function of development time in specimen no. 1 in relation to penetration times of 10 minutes and 20 minutes

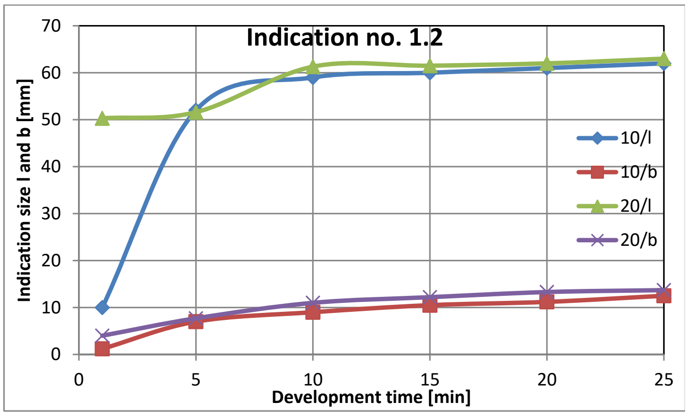

Fig. 6. Size of indication no. 1.2 in the function of development time in specimen no. 1 in relation to penetration times of 10 minutes and 20 minutes

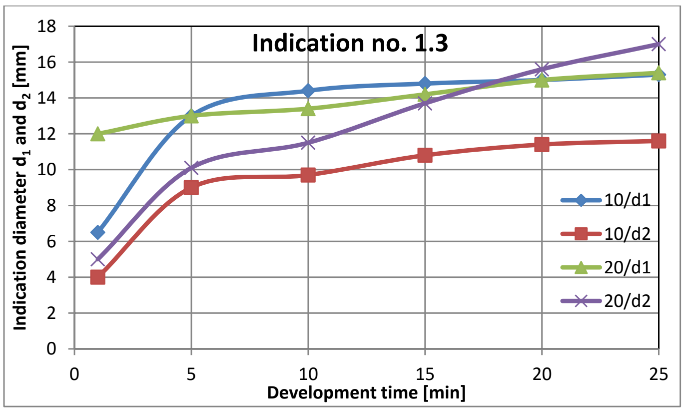

Fig. 7. Size of indication no. 1.3 in the function of development time in specimen no. 1 in relation to penetration times of 10 minutes and 20 minutes

The data presented in the diagrams are provided with symbols where, for instance 10/d1 denotes 10-minute penetration time and the size of indication d1.

Table 2. Percentage increase in indications 1.1, 1.2 and 1.3 in relation to the time of penetration and various times of development

Indication no.	Penetration time [min]	Development time [min]				
		5	10	15	20	25
		Percentage increase in indication [%]				
1.1	10	76	85	92	94	100
	20	46	77	84	90	100
1.2	10	84 / 56	95 / 72	97 / 84	98 / 90	100
	20	82 /56	97 / 80	98 / 89	98 / 97	100
1.3	10	82	90	95	98	100
	20	84 / 60	87 / 68	92 / 81	97 / 92	100

The analysis of the basic test results related to the sizes of indications in the aluminium joint (1.1, 1.2 and 1.3), characterised by a penetration time of 10 minutes and that of 20 minutes revealed the varied dynamics of an increase in indications (see Table 2).

The double results presented in Table 2 refer to linear indications, i.e. the dimension of length l and width b as well as to non-linear indications demonstrating the significant diversification of diameters d1 and d2.

The dynamics of indication development was higher in relation to the shorter time of penetration, i.e. 10 minutes. In relation to both times of penetration, the maximum sizes of indications were obtained after 25 minutes. In addition, slightly greater sizes of indications were obtained in relation to the longer time of penetration, i.e. 20 minutes.

Table 3 presents the sizes of indications 2.1 and 2.2 in specimen no. 2 made of steel and in relation to a penetration time of 10 minutes and that of 20 minutes as well as in relation to various times of development.

The data presented in Table 3 were used to develop diagrams presenting dependences of indication sizes in the function of time in

Table 3. Sizes of indications nos. 2.1 and 2.2 in the steel specimen in relation to penetration times of 10 minutes and 20 minutes and various development times

Indication no.	Penetration time [min]	Indication size [mm]	Development time [min]					
			1	5	10	15	20	25
2.1	10	l	14.0	16.0	17.6	18.4	18.8	19.5
		b	4.6	5.9	7.2	7.6	8.1	9.8
	20	d_1	14.8	15.2	15.9	17.1	18.7	19.5
		d_2	5.0	5.5	6.7	8.0	9.6	10.0
2.2	10	l	11.6	12.0	12.1	12.3	12.3	12.3
		b	1.9	2.2	2.4	2.4	2.4	2.4
	20	l	12.2	13.2	14.0	14.3	14.5	15.0
		b	3.0	3.6	5.2	5.7	6.2	6.5

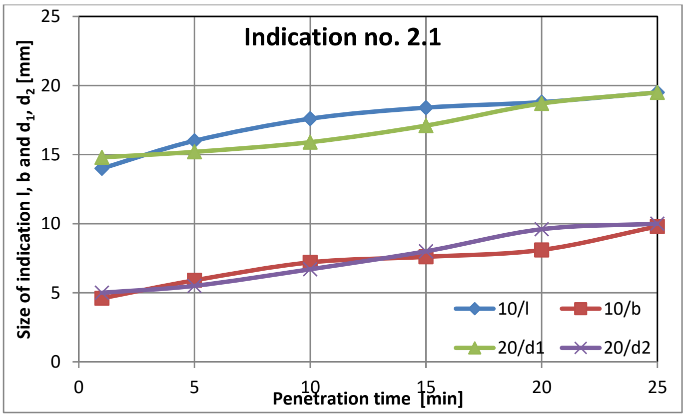

Fig. 8. Size of indication no. 2.1 in the function of development time in specimen no. 2 in relation to penetration times of 10 minutes and 20 minutes

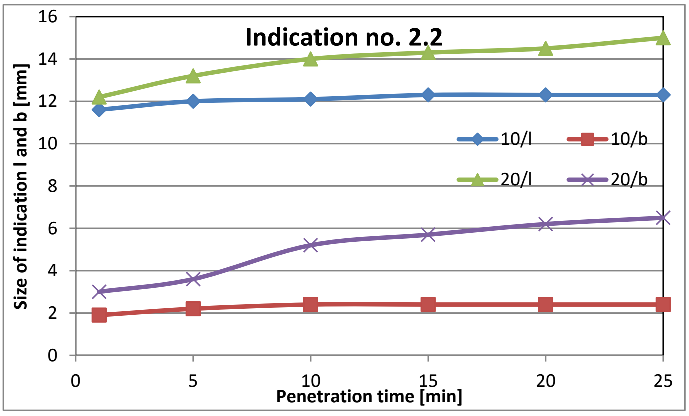

Fig. 9. Size of indication no. 2.2 in the function of development time in specimen no. 2 in relation to penetration times of 10 minutes and 20 minutes

relation to a penetration time of 10 minutes and that of 20 minutes. Figures 8 and 9 present dependences in relation to indication 2.1 and 2.2 respectively.

The analysis of the basic test results related to the sizes of indications in the steel joint (2.1 and 2.2), characterised by a penetration time of 10 minutes and that of 20 minutes revealed the varied dynamics of an increase in indications (see Table 4).

Table 4. Percentage increase in indications 2.1 and 2.2 in relation to the time of penetration and various times of development

Indication no.	Penetration time [min]	Development time [min]				
		5	10	15	20	25
		Percentage increase in indication [%]				
2.1	10	82 / 60	90 / 73	94 / 78	96 / 83	100
	20	78 / 55	82 / 67	88 / 80	96	100
2.2	10	98 / 92	98 / 100	100	100	100
	20	88 /55	93 / 80	95 / 88	97 / 95	100

The dynamics of the development of indications was higher at the initial stage of development in relation to the shorter time of penetration (10 min.). In three cases, the maximum size of an indication was obtained after 25 minutes, whereas in one case, i.e. in relation to specimen 2.2 and a penetration time of 10 minutes, the maximum size of indication was obtained already after 10 minutes (of development). In addition, slightly greater maximum sizes of indications were obtained in relation to the longer penetration time, i.e. 20 minutes.

Concluding remarks

The analysis of the results of the penetrant tests involving the use of the welded joints made of aluminium and structural steel, constant surrounding conditions and various times of penetration led to the following conclusions:

- regardless of whether the time of penetration amounted to 10 or 20 minutes, indications in the joints made of aluminium reached sizes above 90% of the target size after a development time of 15 minutes,
- regardless of whether the time of penetration amounted to 10 or 20 minutes, indications in the joints made of steel reached sizes above 90% of the target size after a development time of 20 minutes,
- in both types of joints, the dynamics of the development of indications was higher in

relation to the shorter time of penetration, i.e. 10 minutes; greater maximum sizes of indications were obtained in relation to the longer time of penetration, i.e. 20 minutes.

The tests followed by the analysis of test results revealed that penetrant tests should involve various development times for different types of materials. In addition, the extension of penetration time decreases the dynamics of the development of indications at the initial phase of development.

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