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LIMITATION OF RISKS OF NON-COMPLIANCE OF WELD METAL POROSITY

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Abstract. *Target quality levels are used in welding production to evaluate the possibility of reaching the desired quality with application of particular welding process, including fitness for purpose based upon defects (i.e., porosity of the weld metal). Traditionally target level is assigned after welding ends and is based on obtained properties. This means, it doesn't take into account the number of specimens which were tested (if sampling test is used) and possible consequences of non-compliance with requirements on porosity of weld metal. The paper presents method of calculation of the target quality level of porosity of weld metal. It is based upon analysis of possibilities of production process as well as upon evaluation of consequences of non-compliance with quality requirements. Recommendations for industrial use were developed on assigning the target quality level for different amounts of sampling and possible consequences of non-compliance with requirements to porosity.*

Keywords: *Welding, Porosity, Implementation of Requirements, Quality Level.*

1. INTRODUCTION

Currently in welding production target quality levels on weld metal porosity are assigned basing upon previously obtained results. In practice this means that neither amount of sampling used to test the weld metal porosity, nor the consequences of structure with pores being put into service are taken into account. This is due to lack of methods of calculation which would allow to perform complex evaluation of risks related to weld metal porosity.

Application of methods of evaluation of technological risks related to non-compliance with product quality requirements is a modern tendency in welding industry [1-7]. The best results are obtained using method of analysis of possibilities and consequences of production process faults. In this method technological risks are determined in numbers according to estimated value of priority number of risks. Determination of this number includes evaluation of significance of potential consequences of the structure being put into service, possibility of production process being non-compliant with quality requirements as well as possibility of defects being timely detected.

Unfortunately, no recommendations currently can be found on assigning of target quality levels on weld metal porosity in which amount of sampling and consequences of non-compliance with quality requirements are taken into account.

Objective of research was to develop method of calculation of target quality level at which level of risks would be admissible for compliance with requirements to weld metal porosity.

2. EVALUATION OF TARGET QUALITY LEVEL

Up-to-date standards estimate technological requirements to acceptable weld metal porosity [1]. During production of welded structures usually non-destructive testing of welds is performed using visual, X-ray or ultrasonic methods. Degree of inspection could be 100 % or less with number of sampling Q. In such tests separate sections of welds are analyzed and if pores are detected they are evaluated according to requirements. Every section tested is appointed as compliant or not to requirements. The sections marked as non-compliant are afterwards rejected. This method is currently widely used to evaluate weld metal porosity for separate welds.

According to methods of industrial monitoring of welding processes quality level on weld metal porosity is determined as part of weld sections being non-compliant with quality requirements for a certain period of production time (shift, day, moth, etc.):

$$q_{n/c}^{por} = \frac{n_{por}}{N_{por}} \times 100\% \qquad (1)$$

where n_{por} – number of detected non-compliant (rejected) weld sections; N_{por} – total number of sections on which porosity was determined.

Quality level $q_{n/c}^{por}$ is a possibility of the weld section being non-compliant with requirements to weld metal porosity $p_{n/c}^{por}$. Usually this possibility is calculated using data from industry. If significant increase or any negative tendency for target level on weld metal porosity is observed, search for their origins is performed followed by corrective actions. Origins can be related with violation of welding technology, non-compliance of parent materials and consumables, etc.

The main disadvantage of this widely used method of monitoring of welding production is lack of clear criteria for estimation of target quality level on weld metal porosity. Acceptable quality level is assigned using data previously obtained in industry and requirements of the customer, but risks of weld metal porosity being non-compliant with requirements isn't taken into account. Meanwhile, these risks can be rather significant and should be considered while assigning of target quality level [2].

Method of Failure Mode and Effects Analysis (FMEA) is widely used to analyze risks related with non-compliance with product quality requirements [2-5]. According to this method priority number of risks RPN related with unallowable porosity of welds can be calculated as [4]:

$$RPN = S \times O \times D \qquad (2)$$

where S – rank of value of consequences of weld metal porosity being non-compliant with requirements; O – rank of possibility of weld being non-compliant to requirements to porosity; D – rank of detection of non-compliant porosity of welds (all factors are measured in points).

Value of every rank (S, O, D) is between 1 and 10 points, priority number of risks can be in range 1 to 1000 points. Priority number of risks is a total evaluator of significance of consequences of operation of welded structure non-compliant to requirements to porosity, possibility of obtaining non-compliant weld and possibility of timely detection of non-compliances. Risk is considered to be acceptable if priority number of risks is under 100 points ($RPN^0 \leq 100$).

In general rank values (S, O, D) are taken from referral tables [4], but these tables should be adapted to welding production specifics. Such adaptation can be performed basing on effect of porosity on operational properties of welded joints.

The number and type of pores in weld metal effect density and mechanical properties of welded joint. Degradation of mechanical properties takes place due to slackening of weld cross-section as well as pores acting like stress concentrators. It should be mentioned that effect of pores on mechanical properties in transversal welds is stronger then that on longitudinal ones, especially when operating tensions are relatively low.

Pores decrease density of weld metal, pores located on the surface can also become centres of attack is corrosion can take place.

Criteria for estimation of ranks of significance of consequences of welds being non-compliant to requirements to porosity are given in Tab. (1). They were developed taking into account type of loads in welded joints, operation conditions and purpose of the whole structure.

Table 1. Rank of significance of consequences of non-compliance with requirements to weld metal porosity

Criteria of rank assigning	S, points
Exceeding of acceptable porosity is a potential risk for life and safety of people, corruption or loss of tightness occur in a flash. Example: exceeding of acceptable porosity in welded joints operating under changing loads in high-pressure vessels, pipelines, containers for dangerous liquids and gases, bearing structures made of high-strength steels, etc.	10
Exceeding of acceptable porosity is a potential risk for life and safety of people; corruption or loss of tightness occur after changes of shape, colour, dimensions of structure, different physical phenomena (like fogging, sounds) which act like warning. Example: exceeding of acceptable porosity in welded joints operating under mainly static loads in high-pressure vessels, pipelines, containers for dangerous liquids and gases, bearing structures made of common steels, etc.	9
Exceeding of acceptable porosity causes loss of tightness or welded structure corruption without risk for life and safety of people. Example: exceeding of acceptable porosity in welded joints operating under changing loads in machine parts, vessels, pipes, containers for non-dangerous liquids and gases, non-bearing structures made of high-strength steels.	8
Exceeding of acceptable porosity causes slight violation of tightness or shape of the welded structure	7

without risk for life and safety of people. Example: exceeding of acceptable porosity in welded joints operating under mainly static loads in machine parts, vessels, pipes, containers for non-dangerous liquids and gases, non-bearing structures made of common steels, ship frames, etc.	
Welded joint is a part of complex technical system and isn't directly participating in its operation. Exceeding of acceptable porosity leads to weld corruption or loss of tightness, but this doesn't effect operation properties of the structure in whole. Repairing is obligatory. Example: working welds in transport frames operating under changing loads.	6
Welded joint is a part of complex technical system and isn't directly participating in its operation. Exceeding of acceptable porosity leads to weld corruption or loss of tightness, but this doesn't effect operation properties of the structure in whole. Repairing is optional. Example: welds in transport frames.	5
Exceeding of acceptable porosity leads to changes to the worse of structure appearance, comfort of operation which are considered to be significant by 75 % of users. Structures require additional treatment. Example: non-working (joining) longitudinal welds.	4
Exceeding of acceptable porosity leads to changes to the worse of structure appearance, comfort of operation which are considered to be significant by 50 % of users. Structures require additional treatment. Example: non-working (joining) longitudinal welds.	3
Exceeding of acceptable porosity leads to changes to the worse of structure appearance, comfort of operation which are considered to be significant by 25 of users. Structures require additional treatment. Example: non-working (joining) longitudinal welds.	2
Exceeding of acceptable porosity doesn't lead to any significant consequences	1

Rank S can be assigned according to data presented in Tab. (1) depending on structure designation and operation conditions. Rank of possibility of obtaining non-compliant with requirements weld (O) is determined according to quality level $q_{n/c}^{por}$. Rank of possibility of non-compliant joint being detected (D) depends on number of sampling used for porosity control Q.

Rank of possibility of joint being non-compliant with requirements to porosity O is related with quality level $q_{n/c}^{por}$ [7]:

$$O = \left(\frac{q_{n/c}^{por}}{5 \times 10^{-3}} \right)^{1/8,548} \tag{3}$$

Rank of detection D and number of sampling in porosity control Q are related as well:

$$D = \frac{1}{0,733} \times \ln \frac{Q}{1 \times 10^{-4}} \tag{4}$$

Taking into account relation (2):

$$RPN\left(S, q_{n/c}^{por}, Q\right) = S \times \left(\frac{q_{n/c}^{por}}{5 \times 10^{-3}} \right)^{1/8,548} \times \frac{1}{0,733} \times \ln \frac{Q}{1 \times 10^{-4}} \tag{5}$$

Target quality level on porosity $q_{n/c}^{por}$, which limits priority risk number by RPN^0 can be calculated using the following formula:

$$q_{n/c}^{por} \leq 5 \times 10^{-3} \times \left(\frac{0,733 RPN^0}{S \times \ln \frac{Q}{1 \times 10^{-4}}} \right)^{8,548} \tag{6}$$

Calculations of target quality levels were performed for different numbers of sampling Q and ranks of consequences S, their results are given in Tab. (2). These quality levels ensure the priority risk number being limited to RPN^0=100.

Table 2. Target quality level with priority number of risks limited by RPN≤RPN^0=100

Q, %	Target quality level on weld metal porosity $q_{n/c}^{por}$, %									
	S=10	S=9	S=8	S=7	S=6	S=5	S=4	S=3	S=2	S=1
100	0,3	0,7	1,8	5,6	20,9	n/e	n/e	n/e	n/e	n/e
90	n/a	n/a	n/a	0,2	0,7	3,1	20,9	n/e	n/e	n/e
80	n/a	n/a	n/a	n/a	0,3	1,4	9,2	n/e	n/e	n/e
70	n/a	n/a	n/a	n/a	0,2	0,9	5,9	69,3	n/e	n/e
60	n/a	n/a	n/a	n/a	0,1	0,7	4,4	51,3	n/e	n/e
50	n/a	n/a	n/a	n/a	0,1	0,5	3,5	40,9	n/e	n/e
40	n/a	n/a	n/a	n/a	n/a	0,4	2,9	34,1	n/e	n/e
30	n/a	n/a	n/a	n/a	n/a	0,4	2,5	29,3	n/e	n/e
20	n/a	n/a	n/a	n/a	n/a	0,3	2,2	25,8	n/e	n/e
10	n/a	n/a	n/a	n/a	n/a	0,3	2,0	23,1	n/e	n/e

Notes: colour-displayed area contains recommendations for target quality levels of weld metal on porosity.
2. n/a – performing of welding is prohibited, acceptable level of technological risks RPN^0=100 is exceeded.
3. n/e – porosity does not lead to any significant risks (*RPN*<100), no need to estimate target quality level.

In calculations (Tab. (2)) it was accepted that target quality level $q_{n/c}^{por}$<0,1% is impossible to reach in modern welding production. In this case performing of welding isn't allowed due to high technological risks *RPN*>100 (these combinations are marked as 'n/a' in Tab. (2). If value of target quality level $q_{n/c}^{por}$ exceeds 99 %, such quality level can be guaranteed in any type of modern welding production. In this case there is no need to assign the target quality level and to control the weld metal porosity (these combinations are marked as 'n/e' in Tab. (2). Technological risks in this case will not exceed RPN^0=100.

Data from Tab. (2) together with Eq. (6) can be used in industry to ensure compliance with international standards in field of fusion welding [3] as well as in design of welded structures and development of welding procedures and quality assurance programmes.

3. CONCLUSIONS

1. Calculations of target quality levels on weld metal porosity were performed for welds with different values of rank S of possible consequences of weld being non-com-pliant with requirements to porosity. It was shown that in case of S = 1 or S = 2 there's no need to assign target quality level on porosity and technological risks are very low. In welding of critical structures with rank S equal to 10, 9 or 8 the 100 % porosity testing should be performed; quality levels $q_{n/c}^{por}$ do not exceed 0,3 %, 0,7 % and 1,8 %.

2. The developed method can be used to determine target quality levels on weld metal porosity which allow to obtain acceptable level of technological risks with pre-defined number of sampling and known consequences of non-compliant structure being put into service. Target quality level calculations can be used by companies working according to ISO 9001:2008 and its analogs for different branches of industry.

3. Further research will be focused on development of methods of evaluation of tendency of materials to pore formation. This will allow to assign target quality levels on stage of production preparation with limited pool of experimental data.

4. REFERENCES

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5. RESPONSIBILITY NOTICE