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CONDITIONS OF THE SUPERVISED RISK IN THE ZINC COATING PROCESSES

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Both chemical pretreatment of the steel surface and immersing the steel element in the molten zinc make the hot-dip galvanisation process highly risky one. Those risk conditions can have the influence on performing the expectations of the stakeholders in the process in the sustainability term. That is why it is so important to realise the process in the controlled way. Therefore, the proposed methodology of analysis of the traditional hot-dip zinc coating has covered the identification and the assessment of failures, environmental impacts and effects of occupational health threats. Base on the calculation of their risk, the key-aspects have been pointed which is required by the supervision. In turn one has proposed the conditions of the supervised risk.

Key words: zinc, coating, quality, environmental protection, risk

INTRODUCTION

One of the most popular process among the ones allowing to protect steel elements against the corrosion is hot-dip galvanisation [1-3]. The technological parameters which determine the properties of a zinc coating are first of all the aggressive chemical composition of the zinc, pickling and flux solutions as well as their high temperature [1-3]. Then the process creates special threats both in the environmental and the occupational safety context [3]. In the aspect of quality requirements' fulfilment the assurance of those parameters is necessary which requires its supervision [4].

The awareness of the threats in the process gives the grounds for influencing the safety level, and therefore for shaping the strategy ensuring the maintenance of those threats in the controlled condition or their elimination. The knowledge of those threats requires identification and assessment of the risk connected with the specific effects of those threats. Only the understanding of the risk connected with the process can minimise the probability that the aims of the process have not been achieved. Such an approach should provide the fulfilment of the requirements of ISO 9001:2015, ISO 14001:2015 and ISO 45001:2017 standards [5-7].

In view of the foregoing considerations as the aim of the analysis the preparation of the model of the active approach and its application in the hot-dip galvanisation process has been defined.

METHODOLOGY

The worked out methodology reflects the actions encompassing the monitoring of processes directed on the minimising of quality, environmental and occupational risk. The monitoring includes the identification of the operational criteria, definition of the optimal values and confirmation of the compatibility of the real values with the optimal ones.

Operational criteria mean the crucial operational parameters of the process being directly the subject of the monitoring. Operational parameters should be understood as the technological parameters or the technological features which can be monitored directly or in the indirect way. The starting point for identification of the operational criteria is – based on the describing them values of the risk – the identification of the crucial technological features and the crucial technological parameters.

Indication of the key technological features can be realised with the application of the risk connected with the occurrence of defects, environmental impacts and effects of occupational safety threats (URRq, URRe, URRo). This kind of risk has been described as the dependence between the frequency of defect, environmental impact and effect of the occupational threat occurrence and their importance and expressed as (1):

$$URRq/e/o = PROq/e/o \cdot PRIq/e/o \qquad (1)$$

where the following means:

- URRq/e/o – Quality/Environmental/Occupational unit risk ratio,
- PROq/e/o – Priority ratio of defect/environmental impact/effect of occupational threat occurrence,
- PRIq/e/o – Priority ratio of defect/environmental impact/effect of occupational threat importance.

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The guidance for assessing the effects of occupational threats using the Priority ratio of importance (PRIo) has been shown in the Table 1.

The key-character of the identified defects, environmental aspects and effects of occupational threats is dependent on both maximum values of the Priority numbers and the established values of the Unit risk ratio.

Table 1 **Summary of the guidance for the Priority ratio of occupational effect importance – PRIo.**

PRIo	Criteria of the estimation
1	Injury or occupational illness can appear during the worker's occupational activeness maximum twice
2	Injury or illness can appear during the worker's occupational activeness maximum twice per 5 years
3	Injury or illness can appear during the worker's occupational activeness once per 2 years
4	Injury or illness can appear during the worker's occupational activeness maximum twice per year
5	Injury or illness can appear during the worker's occupational activeness more than once per month

Indication of the key technological parameters can be performed with the involvement of the risk taking into account the influence of the particular technological parameter on the creation of the technological features. This kind of risk – Influence risk ratio (IRR) – has been described as a dependence (I) between the particular technological parameter and the technological feature characterised as the Unit risk ratio (URR), and expressed as (2):

$$IRR = I \cdot \sum_{i=1}^{n} URRi \qquad (2)$$

where the following means:

IRR – Influence risk ratio,

URR – Quality/Environmental/Occupational unit risk ratio,

I – dependence between the particular technological parameter and the particular technological feature.

Those crucial technological parameters and features, indicated in this way, should be treated as the operational criteria.

RESULTS IN THE ZINC COATING PROCESS

The proposed methodology of the monitoring has been applied in the zinc coating process.

The key technological features have been identified for the maximum value of the Priority numbers defined as PROq/e/o = 5 and PRIq/e/o = 5 and the maximum acceptable values of the Unit risk ratio levelled at URRq/e ≥ 15 and URRo ≥ 16. Technological features and the determinants of their key-character: values of the Priority numbers and Unit risk ratio have been compared in the Table 2.

The technological parameters most affecting the zinc coating process in the integrated meaning are the following ones: hydrochloric acid concentration, temperature of acid solution and rising water, time of lasting in acid solution, $ZnCl_2$ and NH_4Cl concentration in the flux.

Table 2 **Summary of the results of the exemplary technological features assessment with indication of the key-character ones in the zinc coating process.**

No.	Technological features	Possible effects of features	Determinants of the key-character		
Quality operational features			PROq	PRIq	URRq
1.	Non homogeneity of the coating	Increased susceptibility to the corrosion, rejection of the product or additional processing	1	**5**	5
2.	Too small thickness of the coating	Increased susceptibility to the corrosion, rejection of the product or additional processing	1	2	2
3.	Cracking of the coating	Lack of the possibility of the application in accordance with the planned purpose, rejection of the product	2	**5**	10
4.	Higher than expected drop of the mechanical properties	Lack of the possibility of the application in accordance with the planned purpose, rejection of the product	1	**5**	5
Environmental operational features			PROe	PRIe	URRe
5.	Emission of the sulphur dioxide	Pollution of the air with the sulphur dioxide, acid rains and soil acidification	**5**	3	**15**
6.	Metal-pickling wastewater and rinsing liquids – industrial accident	Uncontrolled pollution of the soil and water	1	**5**	10
7.	Energy intake	Using-up the natural sources	**5**	2	10
8.	Consumption of zinc and other resources	Decrease of the natural sources	**5**	2	10
Occupational safety operational features			PROo	PRIo	URRo
9.	Slip, fall on the same surface	Fractures and dislocation of the limbs, bruise of the body and the injuries of head	4	4	**16**
10.	Stress	Fatigue and diminishing of the mental and physical efficiency, lowering of the eyesight, hearing and manual efficiency	3	3	9
11.	Contact with the hot surfaces	Thermal burns	4	4	**16**
12.	Hot working conditions	Faints loss of consciousness, overheating of the body	**5**	3	9

Table 3 **Matrix of calculating the significance of the selected technological parameters of the zinc coating process depending on the chosen technological features.**

Technological parameters	Technological features												IRR
	URRq				URRe				URRo				
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
Hydrochloric acid concentration	5(I)	-	10(I)	-	-	10(I)	-	-	9(I)	-	-	-	**34**
Time of lasting in acid solution	5(I)	-	10(I)	5(I)	-	-	10(I)	-	-	-	-	-	30
Temperature of acid solution	5(I)	-	10(I)	-	10(I)	-	10(I)	-	9(I)	9(I)	-	-	**53**
$FeCl_2$ concentration	5(I)	-	10(I)	-	-	10(I)	-	-	-	-	-	-	25
Rinsing time	5(I)	-	10(I)	-	-	-	10(I)	-	-	-	-	9(I)	**34**
Temperature of rising water	5(I)	-	10(I)	-	10(I)	-	10(I)	-	9(I)	9(I)	-	-	**53**
$ZnCl_2$ concentration in the flux	5(I)	-	10(I)	-	-	-	-	10(I)	-	-	-	-	25
NH_4Cl concentration in the flux	5(I)	-	10(I)	-	-	-	-	-	-	-	-	-	15

Table 4 **Summary of the selected operational parameters and their criterions as well as the possibilities of the operational control in the zinc coating process.**

Operational parameter	Operational criteria	Operational control
Splintering of the coating	Zinc bathing temperature, bath endurance time	Assurance of the zinc process parameters preventing the increase of the diffusing zinc amount to the iron and the increase of high fragility layer G in the coating
Higher than planned drop of the mechanical properties	Zinc bathing temperature, pickling time in HCl solution	Assurance of the zinc-coating and etching parameters ensuring obtaining the planned mechanical properties
Emission of the sulphur dioxide	Flow volume, SO_2 concentration	Assurance that the acceptable value of the emitted SO_2, stated in the emission permit, are not exceeded
Metal-pickling wastewater	pH value	Matching the concentration and the reagent amount needed for the acid bath neutralisation
Noise exposure	Noise intensity	Assurance of the individual protection measures
Microclimate – high temperature	Thermal load ratio	Assurances of the proper parameters of the blown air-stream (speed and temperature), of the used ventilation system and defining of the optimal exposure time

The technological parameters of the key-character have been indicated for the minimum values of the Influence risk ratio levelled at IRR $\geq$ 34 according to the Table 3.

The operational parameters identified by the high values of the risk ratios should be supervised. Nevertheless, manner of the realisation of the zinc coating process not always enables their direct control. Thus the monitoring of the process requires the indication of the operational criteria being the subject of the direct control. The exemplary operational parameters and criteria as well as the operational control methods have been shown in the Table 4.

CONCLUSIONS

Monitoring of the process, presented in the paper, is of the authorial character. The worked out methodology of the identification of the crucial operational parameters and indication of the operational criteria in the effect allows for the monitoring.

In the zinc coating process during the identification of the crucial technological features, both high values of the Unite risk ratio (URR) and critical values of the Priority numbers of the occurrence or importance (Pro/PRI) have allowed for the identification of the following key-technological features:

- non homogeneity, too small thickness and cracking, the insufficient adherence of the zinc coating influencing its susceptibility to corrosion,
- the after-pickling wastewater effecting the controlled and uncontrolled contamination of the waters and soils as well as sulphur and nitrogen dioxides, carbon monoxide and particulate matter resulting in pollution of the air, acid rains and soli acidification,
- thermal burns, fractures of the limbs, body contusions and the head injuries, the afflictions and injuries of the musculoskeletal system as well as stress.

In the time of the identification of the crucial technological parameters, base on the highest values of the Influence risk ratio (IRR), hydrochloric acid concentration and temperature, temperature of rising water, time of lasting in acid solution, $ZnCl_2$ and NH_4Cl concentration in the flux have been defined.

The crucial both features and parameters, which have been indicated this way, should undergo the monitoring. Some of the operational parameters can be directly controlled being at once operational criterions, as for example in the case of the pH of metal-pickling waste water. When the direct control is impossible or when the dependence is not direct, the operational parameter requires establishing the operational criterion, like in the case of the increase of the mechanical properties – time of pickling in the HCl solution. In a similar way as the operational criteria can differ, the possibilities of control can also vary adopting the differing solutions.

The proposed model of proactive supervision to ensure the compliance of the realised actions with the planned ones is of the universal character and can be applied in any technological process. In the paper the selected elements of the analysis have been shown, but the effective implementation of the model requires the expert identification and consideration of all operational parameters.

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