Quality assessment of aluminized steel tubes

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Abstract

The results of assessments of the welded steel tubes with the Al-Si coating intended for the motorization needs – are presented in the paper. The measurement of mechanical properties, tube diameters and thickness, internal flash heights as well as the alternative assessment of the weld quality were performed. The obtained results are presented by means of tools available in the Statistica program and macroscopic observations.

Keywords: measurement of mechanical properties, measurement of shape and dimensions, process capacity, aluminized steel tubes

1. Introduction

Continuous development of production methods and processing of tubes and profiles as well as more and more demanding criteria related to their application, are expressed by the increased specified qualitative requirements, which in turn imply endeavours to improve processes and products. Simultaneously, there is a tendency to minimize costs by introducing modern designing, supervising and control methods as well as ensuring a high quality delivery.

Among several methods of production steel tubes without coatings and with coatings e.g. Zn, Al-Si and a large number of investigations of their improvements [1-13], the most often applied is the formation of tubes from strips, joining them by pressure or fusion welding, calibrating and cutting. The process of forming slit tubes of strips allows obtaining round profiles, and more complex shapes. The schematic presentation of the tube production line is shown in Fig. 1 [14].

A charging strip should have not only uniform mechanical properties but should be geometrical and of a good quality surface. Problem of a charging strip thickness tolerance becomes important when taking into consideration effects of tube wall thickness changes in reduction processes, in which its thickening occurs. Attention should be also directed to the process of cutting the strip into the required bands. Special requirements concern the edge quality of strips aluminised on both sides. Examinations indicated [15], that due to the required joint quality any leftovers of aluminium on the surface after cutting are not allowed.

The optimal selection of charge parameters and tools used in the tube forming process decides on a proper material flow and fitting of joining edges, which warrant obtaining a high quality product. Investigations concerning designing, production and processing of tubes, control methods, tools wearing and hazard assessments are presented in several papers [16-18].
The quality assessment of steel tubes with the Al-Si coating, welded by high frequency currents, in respect of obtaining the products fulfilling the client’s requirements concerning features, shapes and dimensions – is the aim of the hereby paper.

2. Experimental Technique

Steel, smooth tubes of the DX52D+AS120 grade with the Al-Si coating, welded by high frequency currents, produced under industrial conditions and intended for the motorisation needs were examined. Tubes of a nominal diameter: \( d_r = 50.8\); 48; 45; 38 mm, a wall thickness \( g_r = 1.5\) mm and a coating thickness on each side: \( g_p = 20-25 \mu \)m were selected for testing. The chemical composition of the steel base is given in Table 1.

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>Cr</th>
<th>Al</th>
<th>P</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.004</td>
<td>0.16</td>
<td>0.011</td>
<td>0.015</td>
<td>0.042</td>
<td>0.009</td>
<td></td>
</tr>
</tbody>
</table>

Requirements concerning a charge material in a form of steel strips are given in references [19-21]. Requirements concerning the investigated tubes, formulated on the bases of clients’ requirements are as follow:
- \( R_e \) – max 300 MPa,
- \( R_m \) - 270 – 420 MPa,
- \( A_{80} \) - min 28%,
- coating thickness on one side - min 20 \( \mu \)m,
- diameter tolerance - +/-0.5% (max +/-0.25 mm),
- tube ends - ends cut perpendicularly to a tube axis, without splinters and feathers trimmed (Max. trim height after saw 0,3 mm),
- tube straightness - according to DIN 2394,
- height of an internal flash - max. 0,3 mm.

During the realisation of investigations the following measurements were carried out: external tube diameter, wall thickness, selected mechanical properties (\( R_e \), \( R_m \), \( A_{80} \)), height of internal flash. An alternative estimation of a weld quality was also performed. Measurements of diameters and thickness of tubes were made by means of an electronic slide calliper and a micrometer screw. The specially constructed instrument measured an internal flash height, while measurements of mechanical properties were carried out according to Standard [22] by the laboratory testing machine. The obtained results are presented in diagrams, histograms, dot diagrams and control cards either acc. to the digital estimation of the \( \bar{X} \) - R type (arithmetic mean – range) or acc. to the alternative estimation of the Np type.

There are three characteristic lines on the control card:
- central line - CL,
- upper control line - UCL,
- lower control line - LCL.

The central line for card \( \bar{X} \) - R is determined from equations:

\[
CL = \bar{X} = \frac{\sum \bar{X}}{k} = \frac{\sum \bar{X}}{n}
\]

\[
\bar{X} = \frac{\sum \bar{X}}{n}
\]

\( \bar{X} \) – mean value from mean values, 
\( \bar{X} \) – mean value, 
\( k \) – number of samples, 
\( n \) – sample size.

Control limits for card \( \bar{X} \) - R are estimated according to the following equations:

for \( \bar{X} \):

\[
UCL = \bar{X} + A_2 \bar{R}
\]

\[
LCL = \bar{X} - A_2 \bar{R}
\]

for R:

\[
UCL = D_4 \bar{R}
\]

\[
LCL = D_3 \bar{R}
\]

Coefficients \( A_2 \), \( D_3 \) and \( D_4 \) are selected from the table of sample size \( n \) [23].

The variable distribution was checked by applying the normal probability diagram. Detailed information concerning construction of the normal probability diagram is presented in papers [23-24].

The central line for card Np is determined from equations:

\[
CL = np
\]

where:
- \( n \) – sample size
- \( p \) – mean value of fraction of inconsistent product in samples

Control limits for card Np are estimated according to the following equations:

\[
UCL = np + 3\sqrt{np(1-p)}
\]

\[
LCL = np - 3\sqrt{np(1-p)}
\]
The next stage was the estimation of the process capacity expressed, among others, by coefficients $C_p$ and $C_{pk}$. The first step, in a similar fashion as in the application of the control card of the $\bar{X}$-R type, is the verification of the variable distribution character. After the verification of data normality, the estimation of the process quality capacity was performed. The measurement results are presented in a form of:

- diagram with the characteristic lines determining the assumed (expected) nominal value and the process tolerance limits (LSL, USL) as well as the histograms,
- coefficients of the process capacity: $C_p$ and $C_{pk}$.

Coefficients $C_p$ and $C_{pk}$ are calculated on the basis of the following dependence:

- Scatter coefficient:
  \[ C_p = \frac{USL - LSL}{6\sigma} = \frac{T}{6\sigma} \]  
  (10)

where:
- USL – upper specification limit (tolerance T),
- LSL – lower specification limit (tolerance T),
- $\sigma$ - standard deviation of process variability (usually unknown and estimated on the basis of a random sample, marked in such situation by symbol $s$).

Coefficient $C_p$ determines the ratio of the tolerance width to the interval of the process variability width and indicates whether the given stable process is potentially capable to perform the specified task. A process is incapable when $C_p<1$ (it is generally required to have $C_p$ equal at least 1.33). This is the so-called potential capacity, since it does not analyse the deviation of the process mean in relation to the final value,

- index of process alignment:
  \[ C_{pw} = \frac{x - LSL}{3\sigma}; \quad C_{pu} = \frac{USL - x}{3\sigma} \]  
  (11)

where:
- $x$ - denotes the process average value.

3. The results and discussion

3.1. Results of tube diameters measurements

During examinations the measurements were made for tubes of diameters: $d_r=50.8, 48, 45$ and 38mm. The results obtained for one diameter are presented in the paper. The normal distribution diagram for a tube diameter $d_r=50.8$mm is presented in Fig. 2.

Since points are situated either along a straight line or in its vicinity the data distribution can be considered the normal distribution. After verifying the distribution normality, the control card of the $\bar{X}$-R type was introduced. It was decided to take 4– element sample each hour. 30 samples were taken. The following values were obtained: LCL=50.738, CL=50.819, UCL=50.9 for $\bar{X}$ and LCL=50.738, CL=50.819, UCL=50.9 for R. These results are presented in the control card of the $\bar{X}$-R type (Fig. 3).

Data for a tube diameter of 50.8 mm are of a normal distribution. The production process of tubes of a diameter 50.8mm is a stable one, thus there is no need of any intervention.

Then the estimation of the process capacity was performed. A production tolerance for tubes of a diameter 50.8mm is equal to $\pm 0.4$mm, which means that LSL=50.4mm, USL=51.2mm. The results are presented in a diagram (Fig. 4).
The process is capable and meets the assumed quality requirements. Since coefficients of the process capacity are: \( C_p = 3.848 \), \( C_{pk} = 3.664 \) there is no need of undertaking corrective measures towards the process. A similar process capacity was determined for tubes of diameters: \( d_r = 38 \text{mm} \) (\( C_p = 1.709 \), \( C_{pk} = 1.689 \)), \( d_r = 45 \text{mm} \) (\( C_p = 1.75 \), \( C_{pk} = 1.69 \)) and \( d_r = 48 \text{mm} \) (\( C_p = 2.014 \), \( C_{pk} = 1.979 \)).

### 3.2. Results of investigations of wall tubes thickness

141 samples were taken for investigations. The production tolerance for tubes of a wall thickness of 1.5mm equals \( \pm 0.2 \text{mm} \). On the basis of the obtained results the histogram was prepared (Fig. 5).

The obtained results indicate that the wall thickness of tubes is within limits required by the client.
Coefficients of the process capacity are: \( C_p = 0.961 \), \( C_{pk} = 0.6961 \). This process is not capable and does not fulfil the assumed quality requirements. Features of a charge strip should be analysed. The diagram indicates that these series of tubes should not have been accepted by the quality control due to strip features. It is possible that this is caused by aging processes, which occurs after the expiry date of the strip. This period is equal 6 weeks for the DX52D + AS steel strip.

### 3.4. Investigation results of the flash height

The results of an mean flash height obtained on the bases of measurements of tubes of diameters \( d_r = 50.8, 48, 45 \) and 38mm, are presented in the diagram (Fig. 9).

Due to the requirements concerning the maximum height of an internal flash being 0.3mm, the process of its removal can be considered the proper one, although several dozen measurements are near this limiting value. Thus, the process of flash removal should be carefully controlled.

### 3.5. Estimation of the weld quality

The alternative estimation of the weld quality was the next stage of investigations. Tests were made by the parallel tube expander (Fig. 10). A total weld fracture (Fig. 11a) or small point cracks the so-called stitches (Fig. 11b) were considered faults.

20 tube samples of a diameter of 50.8mm were taken for examinations (sample size of products was 30), on which bases the weld quality was estimated. The following values were obtained: \( LCL = 0 \), \( CL = 0.7 \), \( UCL = 3.1805 \). The number crossed off in the Np card (Fig. 12) is a number of defective products.

There are no signals on the obtained Np card, which would indicate a process maladjustment. The number of crossed off points does not exceed control limits and other not random events are not seen.
4. Conclusions

The results of quality assessments of high frequency welded steel tubes with the Al-Si coatings are presented in the paper. The following conclusions can be drawn on the bases of the performed investigations:

- Flaw detection analysis, applied as a continuous estimation of the weld tightness is not an adequate method since micro cracks occurring in the weld are not detected due to a low sensitivity of this induction method. A possibility of applying the supersonic inspection should be considered.

- Examination of dimensions and shapes are adequate, however, the lack of a feedback cause the risk of discrepancy of results.

- Examinations of dimensions and shapes are adequate, however, the lack of a feedback does not allow performing immediate corrections.

The results of tube expanding fully expose weld faults, however, the periodicity of performing such tests and the lack of a feedback cause the risk of discrepancy of results.

- Problem of a tube material cracking during expanding should be solved in relation to charge properties and hardening in the expanding process. Deformation during expansion should not exceed the value corresponding to the uniform elongation. The producer has information on the total elongation including the neck. Thus, there is a need of introducing an additional parameter of charge strips into the control. This problem can be also solved by including the neck elongation into the standard description of the total elongation. However, it requires separate material investigations.

References


