Abstract
The paper presents a quality study of the airbag gluing stage, especially the incorrect direction of the silicone cord on the airbag panel. A cortina type airbag is obtained by assembling two panels, which are overlapped and glued with a silicone bead. In the first step, all defects related to the silicone cord, i.e. wrong direction, were analysed based on data collected by the check points of the sewing lines using a QA010 check sheet, for the period of a week. At this point, five areas with a high defect frequency were detected. In the second step, for specified areas we examined the products in order to identify defect causes, respecting a sampling plan. On four random days, fifteen samples were inspected and measured, complying with ISO 9001:2000 and ISO/TS 16949. Then the production process’s ability to meet or exceed preset specifications was evaluated, by measuring the process capability. For problem solving, a “PEM – PEM” diagram was employed. The contributing factors, such as human operators, environment, methods, and materials, were investigated to look for the key areas. Based on a cause – effect analysis, the main non-conformities were underlined and assignable causes of variations detected. Finally a quality improvement plan was proposed taking into account the difficulty of the HSAB production process due to the large size of parts, as well as the cutting stage, silicone bead and pressing and sewing operations.

Key words: airbag, gluing, dimensional analysis, quality control, process capability.

Introduction
The successful use of driver and front passenger airbags as injury protection was soon followed by the introduction in other locations of inflatable cushions required to protect the neck, head or legs from impacts. In the last decade, rear passenger and side curtain airbags have been installed with the aim of higher safety. As the number of installed units increased, production had to follow the trend, but requiring the same level of quality. Nevertheless the tendency observed and reported was a decrease in airbag quality, evidenced by the number of defective or failing airbags, as presented in [1].

An airbag is made from nylon fabric and is specially designed for a specific car and location therein. When a collision between the passenger and airbag occurs, the exhaustion of gas is precisely controlled by several holes created in the airbag, absorbing energy and preventing the bouncing of the occupant. The cushion needs to exhibit high tensile strength when inflated by the high temperature and pressure gas, greater than 181 kg/inch, as measured by the ASTM D 5034 method. Also the fabric is required to have good flexibility and low weight, therefore the thickness is less than 0.04 cm and the weight less than 250 g/m². The woven material must present air permeability less than 0.5 cm³/second measured at a 1.27 cm H₂O pressure difference [2].

Figure 1. QA010 check sheet for piece inspected.

Figure 2. Critical zones detected.
latest, a glue cord is stuck in order to hold and seal the panels after being sewn and finally packed.

The paper is divided into 6 sections, the first one presenting the fault analysis and the second section containing the collected data statistical study, followed by a capability analysis and cause-effect diagram for the glue cord variation.

### Defects analysis and critical points

In the first step, all defects related to the silicon cord (especially wrong direction) were analysed based on data collected from the sewing line check points. In order to establish critical zones with the highest defect frequency, a QA010 check sheet was used, containing a grid numbered from 1 to 12 on the x axis and from A to D on the vertical, as shown in Figure 1. During a week, quality inspectors checked the silicon bead and recorded the defects’ coordinates on the specified sheet. Inspections were performed in adequate conditions: on a flat surface, in good light and with calibrated equipment, complying with ISO 9001:2008 and ISO/TS 16949. At this stage, three areas with high defect frequencies were detected: A7, A4, C11, with five types of critical defects, as seen in Figure 2.

### Statistical process control

In the second stage, for the areas mentioned previously, we inspected the items in order to measure and analyse the variation in the process, respecting the sampling plan. Measurements were performed in adequate conditions: on a flat surface, in good light and with calibrated equipment. During four days, fifteen samples of three randomly selected items were inspected and measured per day. The data recorded were analysed using statistical process control techniques with the aim of measuring variation in the gluing stage and deciding if the process was under control (see Table 1). For each critical point, a Shewhart Xbar and R chart [4] was drawn, as shown in Figures 3 to 12.

### Table 1. Control chart form collected for day 2 and critical point 2.

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>100</td>
<td>102</td>
<td>103</td>
<td>103</td>
<td>100</td>
</tr>
<tr>
<td>Item 2</td>
<td>102.5</td>
<td>102</td>
<td>102</td>
<td>103.5</td>
<td>101</td>
</tr>
<tr>
<td>Item 3</td>
<td>101</td>
<td>101</td>
<td>102</td>
<td>102</td>
<td>105</td>
</tr>
<tr>
<td>Mean</td>
<td>101.17</td>
<td>101.67</td>
<td>100.33</td>
<td>101.00</td>
<td>100.5</td>
</tr>
<tr>
<td>Range</td>
<td>2.50</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Xbar and R charts are used in the case of smaller samples, in the range from 2 to 10 items per sample, as described in [9]. The upper and lower control limits (UCL and LCL) are computed as follows:

\[
LCL_X = \overline{X} - A_2 \cdot \overline{R} \\
UCL_X = \overline{X} + A_3 \cdot \overline{R} \\
LCL_R = D_3 \cdot \overline{R} \\
UCL_R = D_4 \cdot \overline{R}
\]

The constant values of \(A_2\), \(D_3\) and \(D_4\) are contained in Standard ISO 8258 and are relative to the sample size [5]. In our case, their values are 1.023, 0 and 2.575, respectively. UCL represents 3 standard deviations away from the mean; thus the line between zones A/B is 2 standard deviations away:

\[
A/B \ line = \overline{X} \pm A_2 \cdot \overline{R} \cdot \frac{2}{3}
\]

\[
B/C \ line = \overline{X} \pm A_2 \cdot \overline{R} \cdot \frac{1}{3}
\]

Product specifications for the critical zones considered are presented in Table 2. Data collected during the four day study formed a 60 sample group for which lower and upper control limits and 6 sigma zones limits were determined, as shown in Table 3.

### Table 2. Product specifications for critical zones considered.

<table>
<thead>
<tr>
<th>Critical zone</th>
<th>Spec. target, mm</th>
<th>Spec. limit, mm</th>
<th>Lower spec. limit, mm</th>
<th>Upper spec. limit, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>101</td>
<td>15.5</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>96</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>106</td>
<td>20</td>
<td>22</td>
</tr>
</tbody>
</table>

### Table 3. Statistical data for the 5 critical zones.

<table>
<thead>
<tr>
<th>Critical zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>60.10</td>
<td>101.45</td>
<td>15.76</td>
<td>20.95</td>
<td>25.41</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.72</td>
<td>0.98</td>
<td>0.76</td>
<td>2.95</td>
<td>2.99</td>
</tr>
<tr>
<td>X - 3s</td>
<td>57.92</td>
<td>98.51</td>
<td>13.49</td>
<td>12.11</td>
<td>16.45</td>
</tr>
<tr>
<td>X ± 3s</td>
<td>62.27</td>
<td>104.39</td>
<td>18.03</td>
<td>29.79</td>
<td>34.37</td>
</tr>
<tr>
<td>R</td>
<td>0.87</td>
<td>1.11</td>
<td>0.76</td>
<td>4.68</td>
<td>1.76</td>
</tr>
<tr>
<td>UC LR</td>
<td>2.23</td>
<td>2.85</td>
<td>1.97</td>
<td>12.05</td>
<td>4.52</td>
</tr>
<tr>
<td>UCLX</td>
<td>60.98</td>
<td>102.58</td>
<td>16.54</td>
<td>25.73</td>
<td>27.21</td>
</tr>
<tr>
<td>LCLX</td>
<td>59.21</td>
<td>100.32</td>
<td>14.98</td>
<td>16.16</td>
<td>23.62</td>
</tr>
<tr>
<td>A/B line up</td>
<td>60.69</td>
<td>102.21</td>
<td>16.28</td>
<td>24.14</td>
<td>26.61</td>
</tr>
<tr>
<td>A/B line low</td>
<td>59.50</td>
<td>100.69</td>
<td>15.24</td>
<td>17.76</td>
<td>24.21</td>
</tr>
<tr>
<td>B/C line up</td>
<td>60.39</td>
<td>101.83</td>
<td>16.02</td>
<td>22.54</td>
<td>28.01</td>
</tr>
<tr>
<td>B/C line low</td>
<td>59.80</td>
<td>101.07</td>
<td>15.50</td>
<td>19.35</td>
<td>24.81</td>
</tr>
</tbody>
</table>

### Table 4. Chart control rules.

1. Out-of-control points: Any point above or below control limits (3 sigma)
2. One side points: 7 consecutive points on the same side of central line
3. Trend points: 7 points in a row are trending up or down
4. Points close to control limits (A zone): 2 out of 3 consecutive points fall above or below 2 sigma (A zone)
5. Points close to control limits (B zone): 4 out of 5 consecutive points fall above or below 1 sigma (B zone)
6. Alternating points: 14 points in a row are alternating
The R chart was examined before the Xbar chart. The R chart shows that the sample variations are in statistical control, and the Xbar chart needs to be examined to decide if the mean value is also in statistical control [6]. If the variations are not in statistical control, the entire process is considered out of control despite the indications of the Xbar chart.

Precision instability of the process may occur when machine ageing is advanced, staff training inadequate or when semi-finished products are heterogeneous. Unstable adjustment of the process may cause a lack of periodical checks of the machine, a wear limit, an inappropriate setting or uneven material.

Analyzing the R chart for critical point 1, we can see that subgroup 16 is above the control limit, which means that process variability is out of statistical control. It can be observed that samples 22 and 36 are at the zero control limit. From the Xbar control diagram, it can be noticed that means for samples 1, 8 to 11 and 43 are not within the control limits, while the means of samples 44, 45 are below 2 sigma (4th rule). Also samples between 48 and 54 fall under the 2nd rule.

Examining the range chart for point 2, one can observe that all the points are within the control limit for variability; however, samples 8, 21 and 43 are at the lower limit. Samples 8, 9, 10 and 19 have a mean value above the 3 sigma limit, whereas for samples 41, 42, 43, 44 and 45 the means are below 3 sigma. The mean values for samples 10 and 11 follow the 4th rule. For samples 48 to 52 and 21 to 25, the points comply with the 5th rule.

In the case of critical point 3, only sample 2 exceeds the control limit in the R chart, while points 20, 40, 49 and 56 are placed near the limits. From the Xbar, we observe that the means of samples 9, 17, 21, 22, 24 & 25 lie above the control limit and those of samples 45, 47, 52, 55, 57 and 60 are above the 3 sigma line. The mean values of samples 2, 3, 4, 8, 9, 16, 18, 19, 20, 41, 42, 49, 50, 58 and 59 are located close to the control limits of Zone A and fall over the 4th rule.

For critical point 4, examination of the R chart does not provide variability problems, even though the following samples: 5, 6, 12, 23, 28 and 34 are closer to the limits. Inspecting the Xbar control chart for this critical point, we observe that all the samples’ mean values lie within the 3 sigma control limit.

The range points for subgroups 1 and 37 for critical point 3 are situated above the control limit, whereas samples 2, 5, 17, 19, 28, 40 and 43 are very close to the limit. A decreasing trend can be observed between samples 22 and 28. Following the mean chart, we notice that the subgroup means for 10, 34 to 36 and 45 are out of the 3 sigma control lines, while mean values for samples 8, 9, 13 & 14 fall within the 4th rule of zone A. Points from 30 to 39 are on the same side of the mean, as rule 2 suggests.
In conclusion, for critical points 1, 2, 3 and 5, the process is out of control, hence we explored possible causes using SQC specific techniques, such as the Ishikawa diagram, followed by a process quality improvement plan.

Process capability analysis

In the case of critical point 4, where the process is under statistical control, we analysed the capability of the gluing process, thus the Gaussian probability density functions and Taguchi loss function [7] were drawn, as shown in Figure 13. To complete the data analysis and compare the “voice of the customer” with the “voice of the process”, it is necessary to take into account the specification limits. The short term potential capability metrics of the process $C_p$, $C_{pk}$ and Taguchi’s capability metric $C_{pm}$, together with the long term metrics [8] were computed using the following:

$$ C_p = \frac{USL - LSL}{6\sigma_{ST}} = \frac{22 - 18}{6 \cdot 2.736} = 0.24 $$

$$ P_p = \frac{USL - LSL}{6\sigma_{LT}} = \frac{22 - 18}{6 \cdot 2.84} = 0.23 $$

where $\sigma_{ST} = \frac{\bar{R}}{d_2}$ with $d_2 = 1.693$ and

$$ \sigma_{LT} = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n-1}} $$

$$ C_{pk} = \min \left\{ \frac{\bar{X} - LSL}{3\sigma_{ST}}, \frac{USL - \bar{X}}{3\sigma_{ST}} \right\} $$

$$ P_{pk} = \min \left\{ \frac{\bar{X} - LSL}{3\sigma_{LT}}, \frac{USL - \bar{X}}{3\sigma_{LT}} \right\} = 0.14 $$

$$ C_{pm} = \frac{USL - LSL}{6\tau_{ST}} $$

$$ P_{pm} = \frac{USL - LSL}{6\tau_{LT}} = 0.22 $$

where $\tau = \sqrt{\sigma^2 + (T - \bar{X})^2}$

The values of $C_p$ and $P_p$ are smaller than 1 because the specified range is smaller than that of the control limits, thus the process is incapable and the products nonconforming with the specifications [10]. As $C_{pk}$ and $P_{pk}$ are smaller than 1, the process is also off-center, and adjustments are required to move the process to target. The Taguchi $C_{pm}$ and $P_{pm}$ indexes focus on how well the process mean corresponds to the process target; however, the values obtained denote that we can expect a large number of defective products and only a small part will fall within the specifications, as shown in Figure 13.
cation, but with a small value. Capability indices $C_p$ and $C_{pk}$ are greater than 1 due to a wide spread of the engineered limits specified. In the case of critical point 5 we observed that the process in not capable of fulfilling customer requirements due to a $C_p$ less than 1. In these cases, we concluded that the process will generate nonconforming products. However, if the value is small, there are opportunities for process improvements.

### Ishikawa diagram for glue cord variation

For the problem solving stage, an “Ishikawa Diagram” for glue cord variation was employed (see Figure 14). The contributing factors, such as the 4Ms (Machines, Materials, Methods, Manpower), were investigated to look for key areas. Based on cause – effect analyses, the main nonconformities were underlined and assignable causes of variations detected, as presented below:

- the weft coating process was not found to be stable and potential problems were revealed regarding human operators, material, methods and equipment.

- inexperienced workers can cause incorrect placement of fabric panels in pins and wrong handling of the work piece, which can lead to cord disruption.

- an uneven and insufficient pressure occurs because of the metal strips detached from the surface of the pressing table.

- the speed of the pipe can also affect the thickness of the silicon layer.

- incorrect panel assembly occurs as the boards were not placed on all pins.

- the differences between part sizes originate from cutting operations and will increase through the production stages until gluing.

### Conclusions

The paper presents an analysis of the gluing bead process for HSAB. First the critical areas were determined and then measurements made to establish process variability and capability to provide
products according to customer specifications. The measurements were performed in adequate conditions: on a flat surface, in good light, and with calibrated equipment. Based on these results, we determined the points for which the process is not under control and analysed the potential causes. The weft coating process was not found to be stable; problems were revealed regarding human operators, material, methods and equipment.

Finally a quality improvement plan was proposed taking into account the difficulty of the HSAB production process due to the large size of parts, the cutting stage, the silicone bead, and pressing and sewing operations. The improvement proposals include the usage of oval profile pins or mobile pins for the gluing board, the use of a uniform surface press to act simultaneously all over the piece, calibration of the current press and the use of two separate gluing systems.

References


The Laboratory of Biodegradation operates within the structure of the Institute of Biopolymers and Chemical Fibres. It is a modern laboratory with a certificate of accreditation according to Standard PN-EN/ISO/IEC-17025: 2005 (a quality system) bestowed by the Polish Accreditation Centre (PCA). The laboratory works at a global level and can cooperate with many institutions that produce, process and investigate polymeric materials. Thanks to its modern equipment, the Laboratory of Biodegradation can maintain cooperation with Polish and foreign research centers as well as manufacturers and be helpful in assessing the biodegradability of polymeric materials and textiles.

The Laboratory of Biodegradation assesses the susceptibility of polymeric and textile materials to biological degradation caused by microorganisms occurring in the natural environment (soil, compost and water medium). The testing of biodegradation is carried out in oxygen using innovative methods like respirometric testing with the continuous reading of the CO₂ delivered. The laboratory’s modern MICRO-OXYMAX RESPIROMETER is used for carrying out tests in accordance with International Standards.

The methodology of biodegradability testing has been prepared on the basis of the following standards:


The following methods are applied in the assessment of biodegradation: gel chromatography (GPC), infrared spectroscopy (IR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

Contact:

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES
ul. M. Skłodowskiej-Curie 19/27, 90-570 Łódź, Poland
Agnieszka Gutowska Ph. D.,
tel. (+48 42) 638 03 31, e-mail: lab@ibwch.lodz.pl