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Dimensional Analysis and Quality Improvement for Head Side Airbag Gluing Stage

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 silicon 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 nonconformities 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/m^2. The woven material must present air permeability less than 0.5 cm^3/second measured at a 1.27 cm H$_2$O pressure difference [2].

The fabric is generally coated with chloroprene, neoprene or silicon rubber [3] in order to improve the compactness and efficiency. As the coating process is very complicated and difficult to precisely control, production costs are increasing along with compactness problems.

In order to protect passengers in rollover conditions, curtain airbags cover the side windows and must stay inflated longer than other airbags by adding glue to the seam stitching. The manufacture of such an airbag is a difficult process, especially in the case of large items, such as the Head Side Airbag (HSAB). In the production facility considered, the process begins with a raw material, nylon 6.6 threads woven into a fabric, which is siliconed and cut into components. In our case, after cutting, two panels are obtained: one upper and one lower. In the
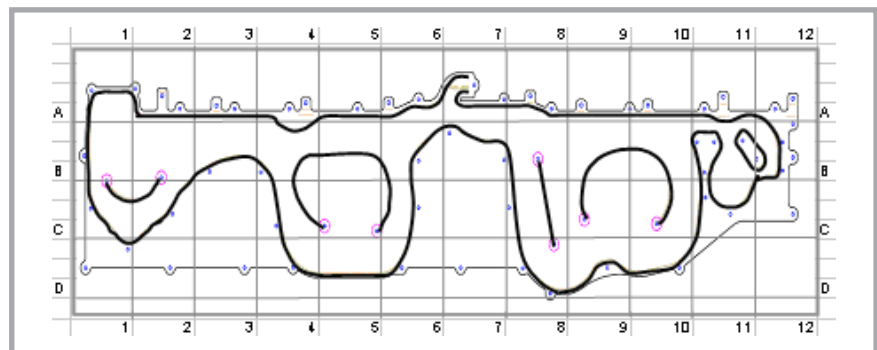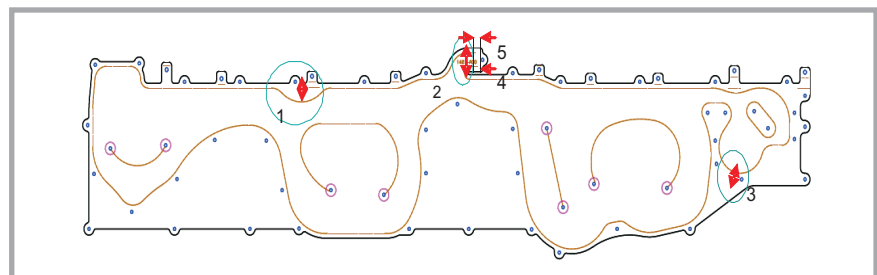

Figure 1. *QA010 check sheet for piece inspected.*

Figure 2. *Critical zones detected.*

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

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Item 1	100	102	103	103	100	101	100.5	100.5	100.5	100.5	102	101	101.5	100	101.5
Item 2	102.5	102	102	103.5	101	101	100.5	101	100	101	101.5	101.5	100	101.5	101
Item 3	101	101	102	102.5	100	101	102	101.5	101.5	101	101.5	102	101.5	101.5	101.5
Mean	101.17	101.67	102.33	103.00	100.33	101.00	101.00	101.00	100.67	100.83	101.67	101.50	101.00	101.00	101.33
Range	2.50	1.00	1.00	1.00	1.00	0.00	1.50	1.00	1.50	0.50	0.50	1.00	1.50	1.50	0.50

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 num-

bered 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***.

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:

$$LCL_{\overline{\overline{X}}} = \overline{\overline{X}} - A_2 \cdot \overline{R} \quad (1)$$

$$LCL_{\overline{\overline{X}}} = \overline{\overline{X}} - A_2 \cdot \overline{R} \quad (2)$$

$$UCL_R = D_4 \cdot \overline{R} \quad (3)$$

$$LCL_R = D_3 \cdot \overline{R} \quad (4)$$

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:

$$\text{A/B line} = \overline{\overline{X}} \pm A_2 \cdot \overline{R} \cdot \frac{2}{3} \quad (5)$$

$$\text{B/C line} = \overline{\overline{X}} \pm A_2 \cdot \overline{R} \cdot \frac{1}{3} \quad (6)$$

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***.

The company quality standards impose 6 rules to identify cases where the process is out of control, using charts for interpretation, as shown in ***Table 4***.

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

Critical zone	1	2	3	4	5
Spec. target, mm	60	101	15.5	20	28
Lower spec. limit, mm	55	96	11	18	26
Upper spec. limit, mm	65	106	20	22	30

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

Critical zone	1	2	3	4	5
Mean	60.10	101.45	15.76	20.95	25.41
Standard deviation	0.72	0.98	0.76	2.95	2.99
X - 3s	57.92	98.51	13.49	12.11	16.45
X + 3s	62.27	104.39	18.03	29.79	34.37
R	0.87	1.11	0.76	4.68	1.76
UC LR	2.23	2.85	1.97	12.05	4.52
UCLX	60.98	102.58	16.54	25.73	27.21
LCLX	59.21	100.32	14.98	16.16	23.62
A/B line up	60.69	102.21	16.28	24.14	26.61
A/B line low	59.50	100.69	15.24	17.76	24.21
B/C line up	60.39	101.83	16.02	22.54	26.01
B/C line low	59.80	101.07	15.50	19.35	24.81

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 trending 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
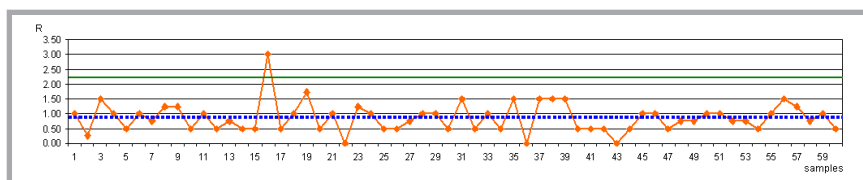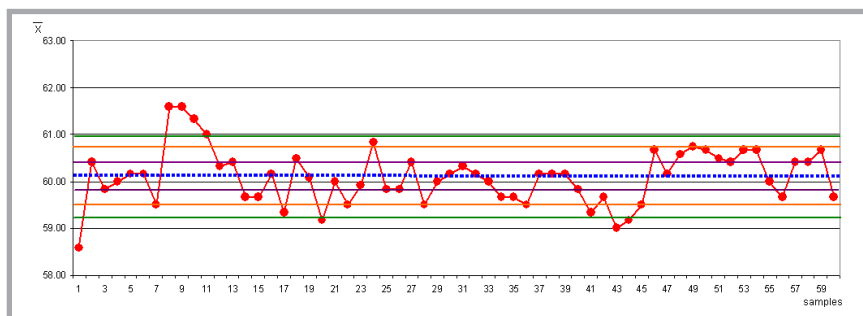

Figure 3. R chart for critical point 1.
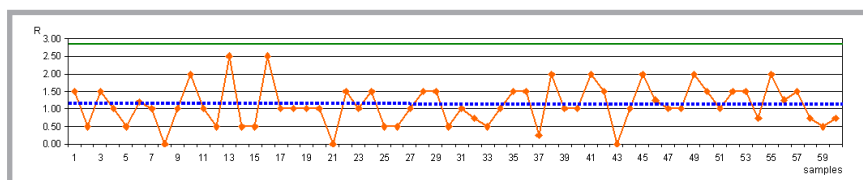

Figure 4. Xbar chart for critical point 1.

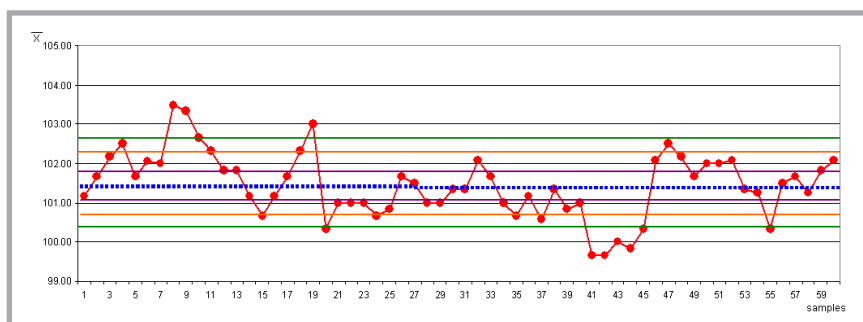*Figure 5. R chart for critical point 2.*
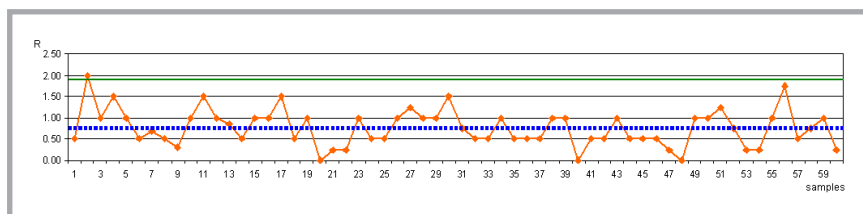

Figure 6. Xbar chart for critical point 2.

Figure 7. R chart for critical point 3.

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 5 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.
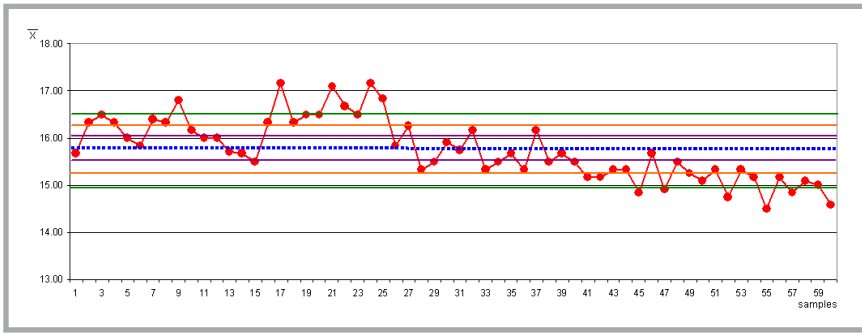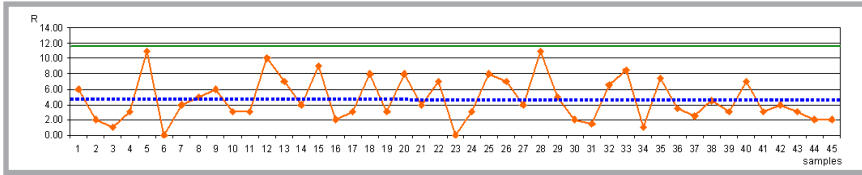
Figure 8. Xbar chart for critical point 3.

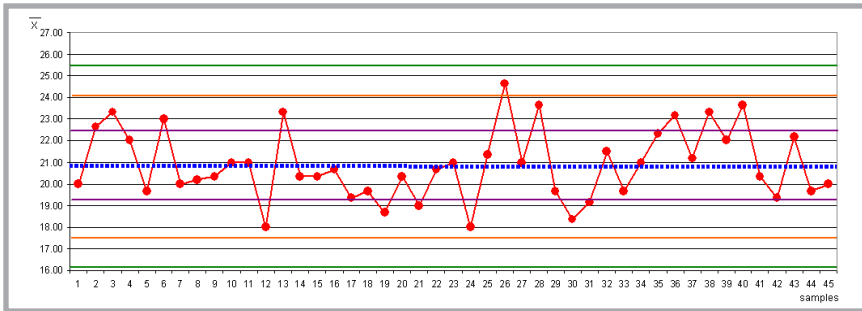
Figure 9. R chart for critical point 4.

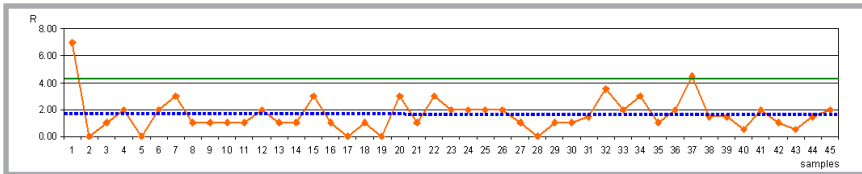*Figure 10. Xbar chart for critical point 4.*

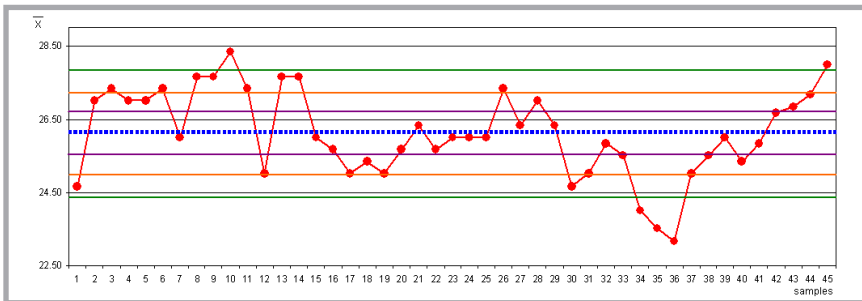
Figure 11. R chart for critical point 5.

Figure 12. Xbar chart for critical point 5.

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:

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

$$P_p = \frac{USL - LSL}{6\sigma_{LT}} = \frac{22 - 18}{6 \cdot 2.84} = 0.23 \tag{7}$$

where $\sigma_{ST} = \dfrac{\overline{R}}{d_2}$ with $d_2 = 1.693$ and

$$\sigma_{LT} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}} \tag{8}$$

$$C_{pk} = \min\left\{\frac{\overline{\overline{X}} - LSL}{3\sigma_{ST}}, \frac{USL - \overline{\overline{X}}}{3\sigma_{ST}}\right\} =$$
$$= \min\{0.35,\ 0.14\} = 0.14 \tag{9}$$

$$P_{pk} = \min\left\{\frac{\overline{\overline{X}} - LSL}{3\sigma_{LT}}, \frac{USL - \overline{\overline{X}}}{3\sigma_{LT}}\right\} = 0.13$$

$$C_{pm} = \frac{USL - LSL}{6\tau_{ST}} = 0.23$$

$$P_{pm} = \frac{USL - LSL}{6\tau_{LT}} = 0.22 \tag{10}$$

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

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*. The Bell curves for zones 1, 2 and 3 show that even if the values of quality characteristics exceed the control limits from the charts, the process is kept in the range of customer specifications. There is a shift of the curve from the target specifi-

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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.

*Figure 13. Bell curve and Taguchi loss function for critical point 4.*
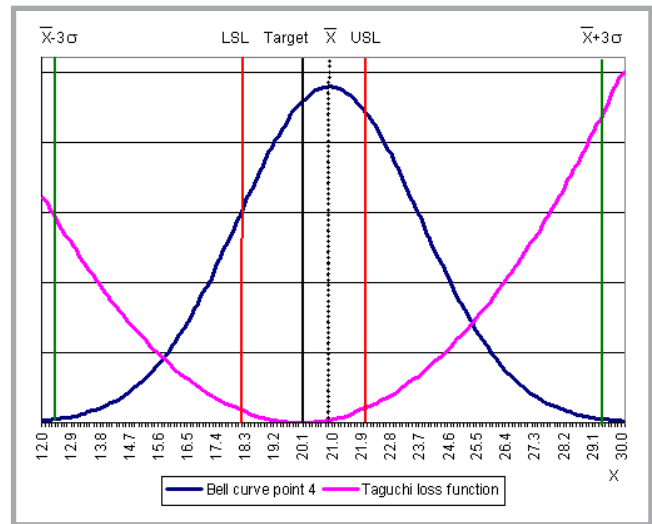
■ inexperienced workers can cause incorrect placement of fabric panels in pins and wrong handling of the work piece, which can lead to cord disruption.

■ 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
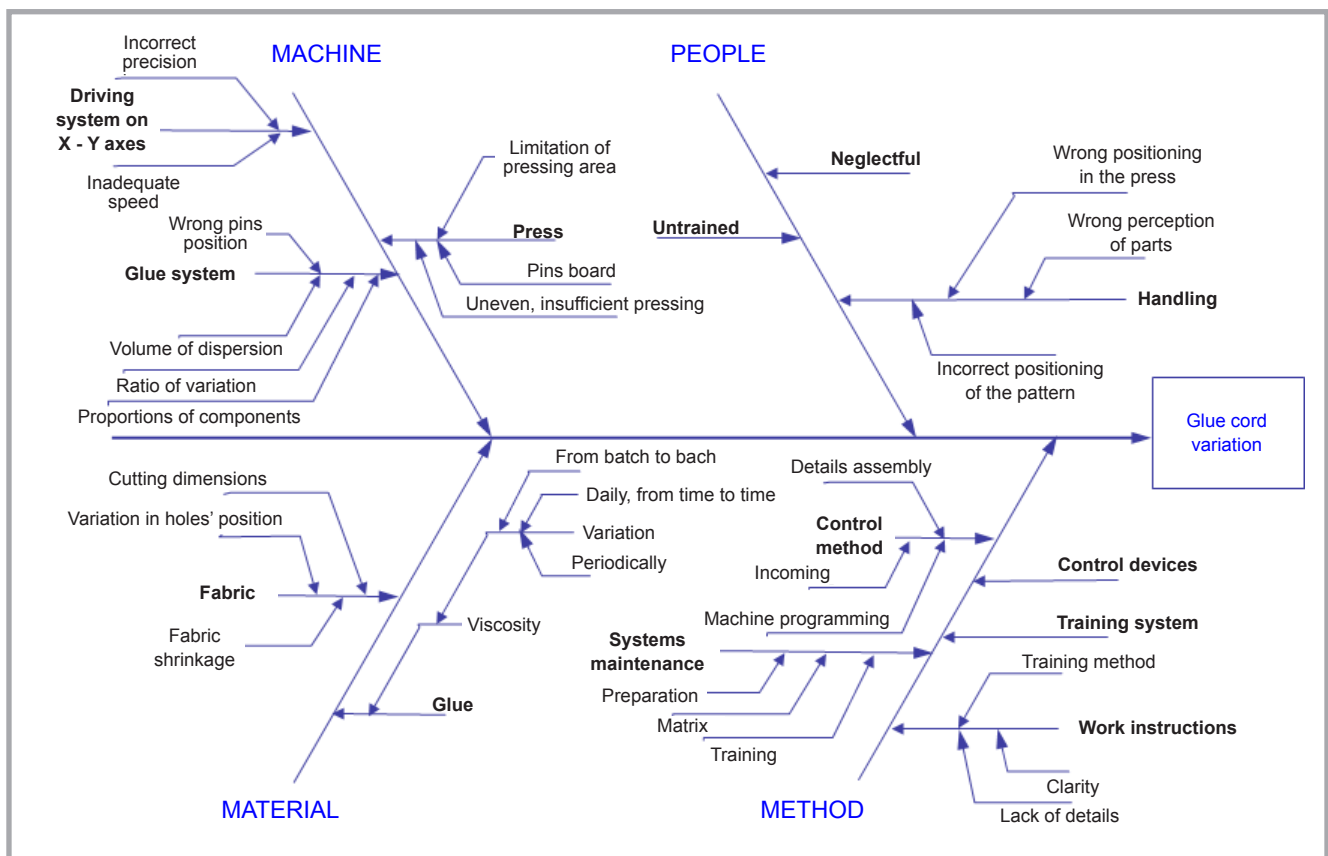
Figure 14. Ishikawa diagram.

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

1. Revkeldt MGC, Labibes K. *Literature survey on in-vehicle safety devices*. TNO Report, 2003.
2. Okada, Yasushi, et al. Airbag device for front passenger's seat. U.S. Patent No. 7,150,470. 19 Dec. 2006.
3. Patents, Silicone Rubber Coating Composition and Airbag. *Journal of Industrial Textiles* 2007; 36, April: 269-278.
4. Chuter AJ. *Quality Management in the Clothing and Textile Industries*. Textile Institute, ISBN 1-870372-48-4, Oxford, 2002.
5. Greasley A. *Operations Management 2nd Edition*. Wiley, ISBN 978-0-470-99761-1, 2009.
6. Kang C, Kvam P. *Basic Statistical Tools for Improving Quality*. Wiley, ISBN 978-0-470-88949-7, 2011.
7. Nahmias S. *Production and Operations Analysis*. 6th Ed. McGraw-Hill/Irwin, ISBN-13: 978-0073377858, 2008.
8. Pyzdek T, Keller P. *The Six Sigma Handbook*. 3rd Ed. McGraw-Hill Professional, ISBN-13: 978-0071623384, 2009.
9. Shewhart WA, Deming EW. *Statistical Methods from the Viewpoint of Quality Control*. Toronto: General Publishing Company, ISBN 0-486-65232-7, 1986.
10. Czarski A. Estimation of process capability indices in case of distribution unlike the normal one. *Archives of Materials Science* 2008; 34, 1: 39-42.

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

LABORATORY OF BIODEGRADATION

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 CO_2 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:

■ **testing in aqueous medium:** 'Determination of the ultimate aerobic biodegrability of plastic materials and textiles in an aqueous medium. A method of analysing the carbon dioxide evolved' (PN-EN ISO 14 852: 2007, and PN-EN ISO 8192: 2007)

■ **testing in compost medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated composting conditions in a laboratory-scale test. A method of determining the weight loss' (PN-EN ISO 20 200: 2007, PN-EN ISO 14 045: 2005, and PN-EN ISO 14 806: 2010)

■ **testing in soil medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated soil conditions in a laboratory-scale test. A method of determining the weight loss" (PN-EN ISO 11 266: 1997, PN-EN ISO 11 721-1: 2002, and PN-EN ISO 11 721-2: 2002).

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

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