International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 2– No.5, February 2012 – www.ijais.org

The use of Statistical Process Control Technique in the Ceramic Tile Manufacturing: a Case Study

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ABSTRACT
Statistical Process Control (SPC) is an effective powerful methodology for analyzing, monitoring, managing, and improving process performance. The purpose of this study is to introduce Statistical Process Control technique in Yazd ceramic tile manufacturing plant in Iran for reducing unwanted ceramic tile defects and wastages. Defects were categorized on their frequencies by examining defective tiles produced in the manufacturing plant. The most important defect was a variety of cracks in different tiles. By implementing control diagrams R, $\overline{X}$ and six-pack for a sensitive parameter, a significant result was observed. Also, system troubleshooting was performed by examining the process and its related machines. After identifying and resolving the given defect and reevaluating the process by the mentioned diagrams, the quality of observed ceramic tiles were improved significantly. Hence, this study presents a complete process to help manufacturer identify defects for process improvement with immediate benefits for the current development cycle in the plant.

General Terms
Improvement of process performance

Keywords
Statistical Process Control; ceramic tile; manufacturing; Pareto chart; Yazd.

1. INTRODUCTION
The objective of implementing quality control techniques is to streamline the manufacturing system by reducing the occurrence of quality related defects, wastages and problems.

Statistical Process Control is a powerful technique for monitoring, managing, analyzing and improving process performance by statistical methods [1]. Ryan [2] defined it as a decision-making technique that uses statistics to monitor the consistency of a production process and the resulting product. The primary application domain for SPC charts is in process control and improvement in manufacturing [3]. SPC considers process variability, and is an essential tool for continuously enhancing product quality [4, 5]. Clearly, SPC has become a popular tool for improvement of quality in manufacturing [1, 6-11]. SPC is an essential management system for business, since it can improve manufacturing processes if applied as described in quality manuals [1].

If it is agreed that a tile has the specifications considered by a customer, then this tile must be produced by a stable or repeatable process. In other words, the production process must have a little variability around the target value with the nominal dimensions of qualitative product specifications. This is a powerful tool for problem solving, being useful for stabilizing the process and improving its efficiency through decreasing its variability. Clearly, SPC can be used for any process in different fields [12]. In particular, ceramic tiles produced by manufacturing plants by new or traditional machines do not meet quality control standards because of improper quality control system by the managements.

Seven SPC tools include: registration sheets, histogram, Pareto chart, cause and effect chart, dispersion chart, defects concentration chart, and control chart. These tools stabilize production processes and improve products quality [13]. The data collected over the period of three months from a commercial tile manufacturing plant in city of Yazd in central desert part of Iran. The collected data included measurements of dimensions for different tile sizes over the selected period.

This study attempts to implement SPC methodology in order to improve product quality in a ceramic tile manufacturing plant in city of Yazd. This factory has been manufacturing ceramic tiles in different sizes since 1974. There are 225 employees who are working in three shifts. The factory has four different lines for automatic press process. There are also two tunnel kilns for firing the ceramic tile products.

This paper presents research work involved in determining the unwanted defects in different tiles produced in the manufacturing plant. The next section offers a discussion of materials and methods. Section 3 presents experimental results. The discussion is presented in Sections 4. Finally concluding remarks are presented in Section 5.

2. MATERIALS AND METHODS
2.1. Pareto chart
Pareto is a bar chart comparing the causes of problems with their frequencies. Based on Pareto principle, 80% of results rise from 20% of factors, in other words, although there may be many factors for existing problems, a few of them are important and most problems can be solved by removing them.

Using Pareto chart, different causes for inappropriate effects can be categorized and it can be shown quickly which category is clearly more important. Six-pack charts include different 6 different packs and are provided in the format of one diagram.

2.2. Control charts
Among seven SPC tools, control diagram is the most important part. The process variations can be controlled using control diagrams, and defective products can be avoided by some preventive actions. Here, it means controls diagrams R, and $\overline{X}$ are the most popular control charts.

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2.3. Control charts R, $\bar{X}$

If X_1, X_2 … X_n is a sample with *n* members for given quantitative attributes, and then the mean for these samples will be as follows:

$$\bar{X} = \frac{x_1 + x_2 + \ldots + x_n}{n} \quad (1)$$

According to the central limit theorem, selecting appropriate sample size, distribution $\bar{X}$ tends to normal distribution. Thus, 99.72% of data is placed within the following control limits.

$$\begin{aligned} ucl &= \mu_{\bar{x}} + 3\sigma_{\bar{x}} \\ cl &= \mu_{\bar{x}} \\ lcl &= \mu_{\bar{x}} - 3\sigma_{\bar{x}} \end{aligned} \quad (2)$$

Hence, control limits for $\bar{X}$ diagram can be determined, having the mean and standard deviation for Xs society [14].

2.4. Statistical principles for R (range) control charts

R is applied as an estimate for standard deviation. The process variability can be controlled, depicting R values on the control diagram. This control diagram is called R diagram. Limits calculations for these diagrams are performed as easily as $\bar{X}$ diagram calculations, assuming that Ri refer to variations between the maximum and minimum data in i-th sample. When the control limits of diagrams were calculated using initial samples, it is necessary to depict the mean and range of samples on $\bar{X}, R$ diagrams and connect the points to each other on diagrams for studying them. If the points on diagrams show an out of control state or a nonrandom pattern, causes must be studied.

2.5. Dispersion chart

Clearly, sampling must be performed during various periods with few numbers so that data would have the most important attribute for comprehensiveness. Random sampling in long period of time is required to obtain better results. It is recommended that the number of data in each group not to exceed from 5. Dispersion diagram show data by the format of its group as well as the data in each group which is in vertical line.

Dispersion diagram indicates the quantitative level of data in each group. It also shows how far data is quantitatively close to each other. It allows us to compare different groups with each other to identify the relationships among them in terms of their component numbers. Finally, it helps to compare process performance during various periods and evaluate it implicitly.

2.6. Histogram

Histogram is a bar diagram in which data can be analyzed. In histogram, many data are categorized in a specific format in order that the problem can be understood and analyzed more simply. It is obvious that data grouping and graphic display will help us significantly to decide logically and effectively. Histogram provides an image for data, by which three following attributes can be understood and observed more simply:

a) Form of data frequency distribution
b) Location with central tendency for distribution
c) Dispersion by distribution development.

Usually, in the best situation, histogram has a bell curve form which is symmetrical and the most of data has been aggregated around the center [15].

2.7. Cp, C_{pk} indices (process capability indices)

Process capability is one of the important items in production. A process may be controlled statistically, but its products may not be in the range being considered by the customer. Using process capability indices, a specific production range can be determined for a component as a fraction of its tolerance range. Production process capability can be identified using C_p index:

$$C_P = \frac{usl - lsl}{6\sigma} \quad (3)$$

$\hat{\sigma}$ is an estimate of standard deviation for the society of production process. It is given by:

$$\hat{\sigma} = \sqrt{n}\,\sigma_{\bar{x}} = \sqrt{\frac{\left[n(\bar{x} - \bar{\bar{x}})\right]^2}{n-1}} \quad (4)$$

Different values calculated for C_p index indicate process state as follows:

1- $C_p>1$ has process capability for producing a component in the range being considered by the customer.
2- $C_p=1$ has process capability for producing a component in the range being considered by the customer with the probability of producing a defective component.
3- $C_p<1$ has not process capability for producing a component in the range being considered by the customer and a defective component is certainly produced by this process [16].

Considering C_p formula, decreasing the range of production process is one of the factors effective on improving C_p index. Thus, the smaller process dispersion or $\hat{\sigma}$ is, the higher production process capability is.

C_p index, independent of production process range is placed in which part of tolerance range, can have numbers larger than one, i.e., it may be $C_p>1$ while all produced components are outside of the tolerance range. Due to this defect in C_p, another index is introduced to consider the production process dispersion, as well as to evaluate the process location to tolerance range. This factor, called C_{pk}, is displayed as follows:

$$c_{pk} = \frac{\min\{(usl - \bar{\bar{x}}), (\bar{\bar{x}} - lsl)\}}{3\hat{\sigma}} \quad (5)$$

In the obove relation, $\hat{\sigma}$ is the standard deviation for production process, also being used in C_p formula. If the production mean is located in the middle of tolerance range, $C_p = C_{pk}$; otherwise, $C_p < C_{pk}$. C_{pk} shows process capability for producing a given attribute more precisely than C_p [16].

3. EXPERIMENTAL RESULTS

In a tile manufacturing plant, both quantitative attributes (as dimensional attributes) and qualitative attributes (as product appearance) are significantly important; perhaps, a key point is to troubleshoot processes correctly and use a powerful tool for solving a problem based on the current need. Pareto principle can be applied for proper system troubleshooting. Sample is a subset of any population size in statistics. Usually, population size is very big. The samples are small and should be in a manageable size. By collecting some samples for defects and their statistical analysis, we can introduce major factors for generating defects so that defects can be removed. For this purpose, 588 samples were collected from the whole defects. In the following, Pareto diagram drawn by Minitab is illustrated. No 1 to 6 denote (Fig. 1) for cracks, broken verge, print and decoration defects, broken edge, defects for underneath glaze, and being shadowy respectively.

As it is observed (Fig.1), defects have been ordered by descending frequency. Among obtained 588 samples, defects include types of cracks (60.9%), broken verge (9.9%), print and decoration defects (9.4%), broken edge (8%), defects for underneath glaze (5.4%), being shadowy (3.9%) and other cases (2.6%).

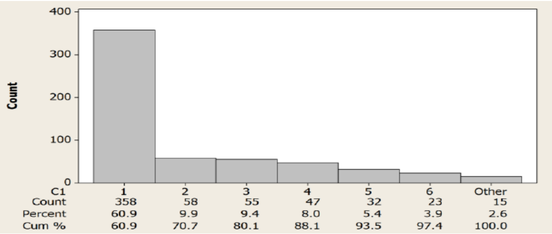

Fig 1: Pareto chart for defects numbers and frequencies percentage

Clearly, Pareto principle is true here, i.e., about 61% of problems occur only due to one of these factors (types of cracks) and resolving this problem can lead to the most effective improvement and cost saving.
Considering above issues, the parameter for crack types was analyzed as the greatest cause for creating tiles defect, which was associated with pressing machines. Thus, six-pack sampling and evaluation were performed on dimensional sizes for tiles 20×20, 40×20 and 40×40. Test results from SPSS software for different tiles are provided in Table 1 as following:

Table 1: Test results from SPSS software for different ceramic tiles

Dimension (cm*cm)	Parameter	Sample (N)	Mean	Std. Deviation	Absolute	Positive	Negative	Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
40*40	Thickness	80	8.5603	0.15111	0.086	0.062	-0.086	0.769	0.595
40*40	Length	80	400.1940	0.59114	0.060	0.041	-0.060	0.535	0.937
40*20	Width	80	200.087	0.28544	0.056	0.041	-0.056	0.499	0.965
40*20	Length	55	399.718	0.56348	0.090	0.090	-0.057	0.671	0.759
40*20	Thickness	55	8.4365	0.08175	0.082	0.063	-0.082	0.607	0.856
20*20	Length	80	200.097	0.29557	0.060	0.041	-0.060	0.535	0.937
20*20	Thickness	50	8.4428	0.08374	0.101	0.078	-0.101	0.717	0.683

Six-pack diagram related to tile 40×40, which had more defect than other tiles, is provided in section 4-1, and 4-2.

4. DISCUSSION

4.1. Thickness of tile 40 × 40

As it is observed in the related six-pack diagram, histogram is not as a bell curve (Fig. 2). It is unsymmetrical; data dispersion is quite high. It shows that data state is not desirable by dispersion and concentration.

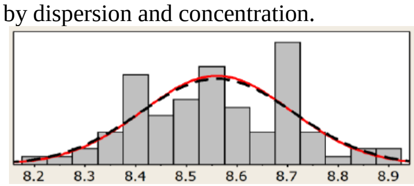

Fig 2: Thickness histogram for tile 40×40

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 16 quintuplet samples, data numbers are far from each other (Fig. 3); this shows data dispersion and process variability. In some quintuplet groups, there are some variations among data.

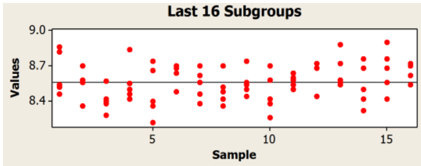

Fig 3: Thickness dispersion chart for tile 40×40

Control diagrams ($\overline{X}$, R) don't show any particular problem (Fig. 4), as all data are in the defined range of UCL and LCL; there is no case such as trend, and data settlement on one side of central line.

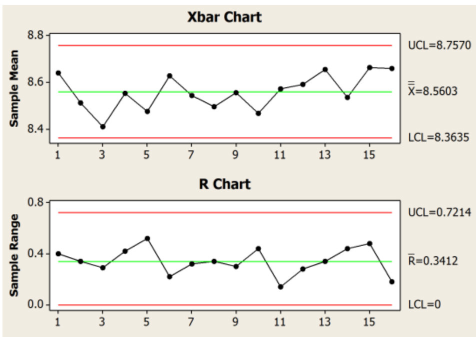

Fig 4: Thickness control chart for 40×40 tiles

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
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However, considering values defined for UCL and LCL for controlling plan, calculated standard deviation is 0.146675, also C_p and C_{pk} are 1.14 and 1.0 respectively (Fig. 5). It shows that the standard range cannot cover values process very well and process capability is close to its desirable value (C_{pk}, C_p>1).

Within	
StDev	0.146675
Cp	1.14
Cpk	1
CCpk	1.14

Fig 5: Indices of process capability for 40×40 tiles thickness

Considering the process by the personnel of repairing unit and machines operators, the effective factors on the instability of pressing process were studied. Third and fourth pressing lines, associated with tile 40×40, have capability for supplying the products in a given range with the probability of producing defective products; implementing statistical process control can be effective for decreasing wastage.

4.2. Length of 40 × 40 tiles

As related six-pack diagram indicates, histogram is in the form of a bell curve (Fig. 6); most of the data are concentrated on the mean and almost there is no asymmetry in the diagram. It shows that the process normality is desirable and data concentration has tended towards the mean. Clearly, the related curve is very close to normal distribution.

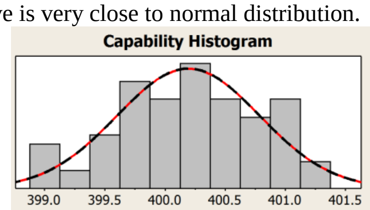

Fig 6: Length histogram for 40×40 tiles

In the dispersion diagram (Last Subgroups) obtained from 16 quintuplet samples (Fig. 7), the process has less variability than its previous position and in these groups. Also, data values are closer to each other. This diagram shows that data has been distributed symmetrically on both sides of the central line, except a few groups being located successively above the central line in sampling.

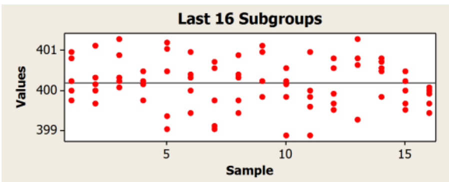

Fig 7: Length dispersion chart for 40×40 tiles

In the control diagram (R, $\overline{X}$), there is no particular issue because all data are in the defined range of UCL and LCL (Fig. 8). Data settlements on one side of the central line are not observed.

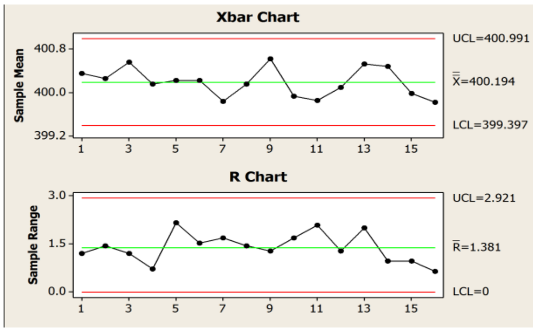

Fig 8: Length control chart for 40×40 tiles

Considering values defined for UCL and LCL for controlling plan (Fig. 9), calculated standard deviation is 0.593889, also C_p and C_{pk} values are 1.12 and 1.01 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

Within	
StDev	0.593889
Cp	1.12
Cpk	1.01
CCpk	1.12

Fig 9: Indices of process capability for 40×40 tiles length

Followings are six-pack diagrams (Sections 4-3 to 4-7) related to different tiles which had fewer defects:

4.3. Length of tile 20 × 20

One-Sample Kolmogorov-Smirnov Test shows that test distribution is normal (Table 1). As it is observed in the related six-pack chart (Fig. 10), histogram is as a bell curve. It is symmetrical; data dispersion is quite low. It shows that data state is desirable by dispersion and concentration.

In the control chart (R, $\overline{X}$), there is no particular issue because all data are in the defined range of UCL and LCL, and data settlements on one side of the central line are not observed.

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 16 quintuplet samples, there is not any unusual observation.

Considering values defined for UCL and LCL, standard deviation is 0.296945, also C_p and C_{pk} values are 1.12 and 1.01 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

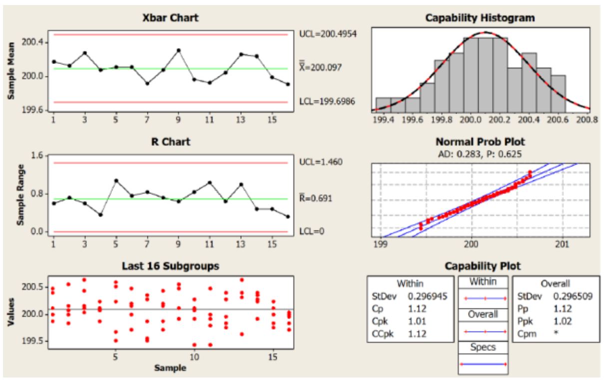

Fig 10: Six-pack charts for length of 20×20 tiles

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
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Volume 2– No.5, February 2012 – www.ijais.org

4.4. Width of 40 × 20 tiles

One-Sample Kolmogorov-Smirnov Test shows that test distribution is normal (Table 1). As it is observed in the related six-pack chart (Fig. 11), histogram is as a bell curve. It is symmetrical; data dispersion is quite low. It shows that data state is desirable by dispersion and concentration.

In the control chart (R, $\bar{X}$), there is no particular issue because all data are in the defined range of UCL and LCL; cases such as trend, and data settlement on one side of the central line are not observed.

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 16 quintuplet samples, there is not any unusual observation.

Considering values defined for UCL and LCL, calculated standard deviation is 0.288643, also C_p and C_{pk} values are 1.15 and 1.05 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

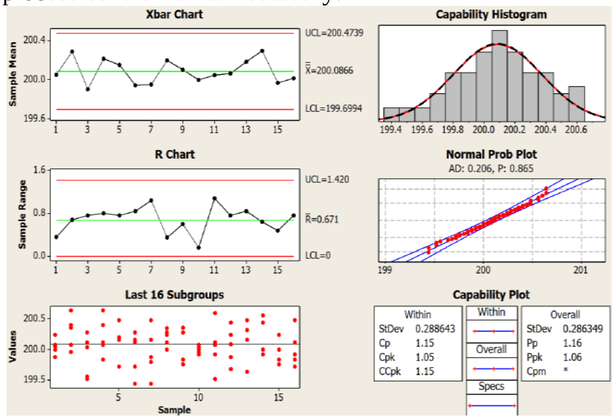

Fig 11: Six-pack charts for width of 40×20 tiles

4.5. Length of 40 × 20 tiles

One-Sample Kolmogorov-Smirnov Test shows that test distribution is normal (Table 1). As it is observed in the related six-pack chart (Fig. 12), histogram is as a bell curve. It is symmetrical; data dispersion is quite low. It shows that data state is desirable by dispersion and concentration.

In the control chart (R, $\bar{X}$), there is no particular issue because all data are in the defined range of UCL and LCL; cases such as trend, and data settlement on one side of the central line are not observed.

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 11 quintuplet samples, there is not any unusual observation.

Considering values defined for UCL and LCL in the standards for controlling plan, value calculated for the process standard deviation is 0.555052, also C_p and C_{pk} values are 1.2 and 1.03 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

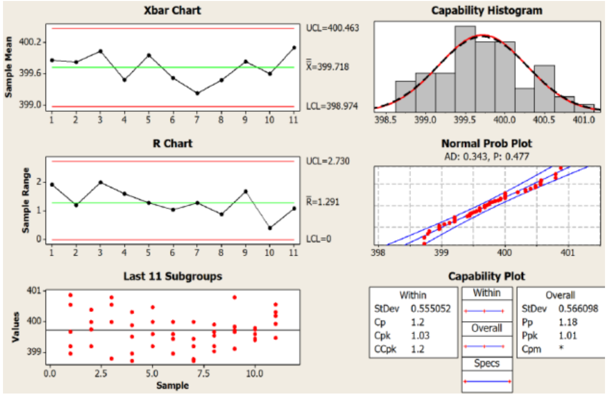

Fig 12: Six-pack charts for length of 40×20 tiles

4.6. Thickness of 20 × 20 tiles

One-Sample Kolmogorov-Smirnov Test shows that test distribution is normal (Table 1). As it is observed in the related six-pack chart (Fig. 13), histogram is as a bell curve. It is symmetrical; data dispersion is quite low. It shows that data state is desirable by dispersion and concentration.

In the control chart (R, $\bar{X}$), there is no particular issue because all data are in the defined range of UCL and LCL; cases such as trend, and data settlement on one side of the central line are not observed.

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 10 quintuplet samples, there is not any unusual observation.

Considering values defined for UCL and LCL in the standards for controlling plan, value calculated for the process standard deviation is 0.0746473, also C_p and C_{pk} values are 1.34 and 1.08 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

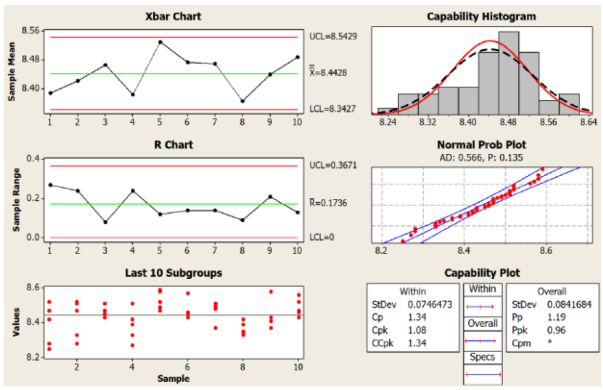

Fig 13: Six-pack charts for thickness of 20×20 tiles

4.7. Thickness of 40 × 20 tiles

One-Sample Kolmogorov-Smirnov Test shows that test distribution is normal (Table 1). As it is observed in the related six-pack chart (Fig. 14), histogram is as a bell curve. It is symmetrical; data dispersion is quite low. It shows that data state is desirable by dispersion and concentration.

In the control chart (R, $\bar{X}$), there is no particular issue because all data are in the defined range of UCL and LCL; cases such as trend, and data settlement on one side of the central line are not observed.

As dispersion diagram (Last Subgroups) indicates, in some groups of obtained 10 quintuplet samples, there is not any unusual observation.

Considering values defined for UCL and LCL in the standards for controlling plan, value calculated for the process standard deviation is 0.0725346, also C_p and C_{pk} values are 1.38 and 1.09 respectively. It shows that the standard range can cover the process slightly well; the process capability is close to its desirable value (C_{pk}, C_p>1) and more statistical process control is not necessary.

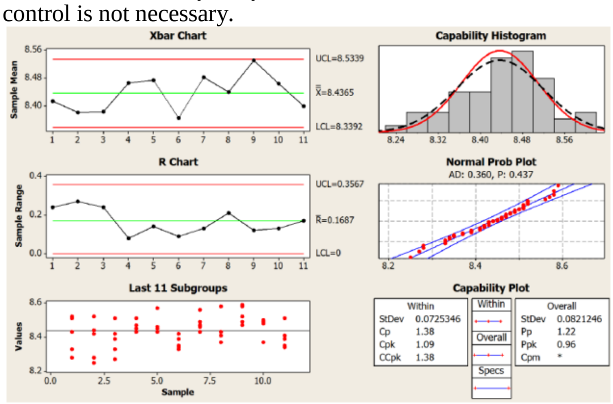

Fig 14: Six-pack charts for thickness of 40×20 tiles

5. CONCLUSION

SPC helps to have better process and decision by collecting required data, deriving information from data, and learning from past mistakes during the manufacturing process of tiles. According to the process, Pareto analysis, pressing defects, as well as pressing attributes recognition, and considering machines capabilities, it was found that third and fourth pressing lines, associated with 40 × 40 tiles, had potential to manufacture the products in given ranges with possibility of having defective products, thus implementing statistical process control was proposed in order to reduce defects.

Defects from 588 different samples included as: types of cracks (60.9%), broken verge (9.9%), print and decoration defects (9.4%), broken edge (8%), defects for underneath glaze (5.4%), being shadowy (3.9%) and other cases (2.6%). Clearly, Pareto principle is true here, i.e., about 61% of problems occur only due to one factor (types of cracks).

Hence, the parameter for crack types was analyzed as the greatest cause for creating tiles defect, which was associated with pressing machines. Thus, six-pack sampling and evaluation were performed on dimensional sizes for different tiles of 20×20, 40×20 and 40×40. Reviewing the above cases indicates that applying a powerful preventing and improving maintenance and repairing system can prevent from many additional expenses to be imposed on the system. Finally, it was decided to develop and implement the appropriate SPC frequently in the manufacturing plant to minimize ceramic tile waste.

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