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New Laser Surface Analyzer for Class A Compression Molded Products

By

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Abstract

The Advanced Laser Surface Analyzer (ALSA) is the result of continuing development of surface smoothness analysis utilizing reflected laser lines to evaluate the surface smoothness of a part or panel. With the aging of the LORIA surface analyzer system making the equipment obsolete, the need for a replacement using current technology was seen. The new surface analyzer system uses a current computer, diode laser, solid state laser line control devices, a Charge Coupled Device (CCD) for image capturing, and a MS Windows style environment for the software creating improvements in resolution, speed and ease of use. These improvements were achieved while maintaining an excellent correlation with the surface waviness numbers generated by the LORIA, the current standard for measuring long term surface waviness. The Gage Repeatability & Reliability (GR&R) and Correlation studies to validate the system were run utilizing 12 panels and 3 operators. The long term surface waviness of the panels ranged from flat black glass to structural SMC with a wide range of surface waviness in between. Orange Peel is another aspect of surface quality that can be measured by this system. These values were confirmed to correlate to a standard set of DuPont orange peel standards. The DOI value has been recalculated using the slope of the intensity curve and the width of the line to correlate to a visual image analysis procedure. The new "Windows" style software is more user friendly than before and creates a summary of the data from a series of panels.

Background

One of the early challenges to evaluating surface smoothness on a fiberglass reinforced thermoset part was to generate a surface smoothness number that would correlate with the ranking of a series of parts rated by personal observation. The Laser Optical Reflected Image Analyzer (LORIA), was developed in the mid 1980s to address that lack of instrumentation. It would assign a numeric value to the surface smoothness of a part or panel by analyzing 21 images of a laser line reflected from a part and averaging the deviation of the reflected line from a best fit regression line. The system took about a year and a half to develop and used a 286 computer and a black and white image capture system to analyze the surface of the part or panel and a dot matrix printer to print out the data. The LORIA system was patented; USP 4,853,777 filed January 29, 1988 and issued August 1, 1989. It received an R&D 100 Award in 1989. LORIA units were sold to OEMs, custom compounders, molders, and raw material suppliers.
The system would project a line of laser light onto a part or panel. See Figure 1. The reflected image of that line could be seen on a screen located to receive the reflected line. A video camera was used to capture the image on the screen. The computer and software were used to digitize the line into an array of data representing the reflected line. The center point of each column in the data array was identified and that data was used to represent the line. A polynomial regression analysis was run on the data to determine the best fit line. The amount of deviation between the reflected line and the best fit line was calculated, accumulated, and used to calculate the "Ashland Index" number, a value for long term surface waviness. Additional calculations were preformed on the data to generate the "Orange Peel" and "Distinctness of Image" (DOI) values.

Long Term Surface Waviness Index Number

The new version of the surface analyzer was designed to emulate the surface smoothness number the old unit calculated because some OEMs like General Motors and Volvo have used the Surface Index Number as a part of their material acceptance specifications for defining the minimum acceptable smoothness. The old system has become obsolete. The 286 computers and associated hardware are difficult, at best, to repair or replace. The controllers for the modification of the laser beam into a line and to advance the line on the panel are no longer made, and there is not a direct replacement part made for them. As our unit and the other units have aged, they require more and more maintenance, and the sources of spare parts have dwindled. Because the LORIA had become a vital part of the development efforts for low profile additives, the need to replace this system with one with equivalent capabilities was evident. See Figure 2 for the new look. The unit was built and new software was written in Visual Basic to simulate the old system and to generate a surface smoothness number that correlated with the old system's Ashland Index number. See Figure 3 for the new look of the main screen. A set of 12 panels was used to do both the surface smoothness index Correlation study and a Gage Repeatability and Reproducibility (GR&R) study. A variety of panel types was used to yield a wide range in the surface smoothness index numbers. These panels included a black glass panel for an ultra smooth surface, several automotive "Class

A" panels, several heavy truck "Class A" panels, and several structural grade panels.

Gage R&R Study - ANOVA Method

Because of the use of Design for Six Sigma (DfSS), a measurement system analysis needed to be run on the new instrument. A Gage Repeatability and Reproducibility (Gage R&R) study was run using the 12 panels described above and 3 operators. Each operator ran each of the 12 panels in random order 3 times. The data was analyzed using the Minitab ™ statistical program. The results of the Gage R&R ANOVA analysis on the ALSA long term waviness index shows that 99.76% of the total variation is due to "Part-to-Part" variation and only 0.24% is due to "Total Gage R&R". This large percentage of variation in to "Part-to-Part" is what you will see from a good gage. The 0.24% is well below the 2% floor for that metric. The % Study Variation of the Total Gage R&R is one of the most important numbers shown in the Gage R&R Report. Its value of 4.93 is far below the 14 limit for that metric and therefore the unit is a good measurement tool. The details of the Gage R&R variation contribution analysis are shown in Figure 4, while the details of the Gage R&R Report study variation are shown in Figure 5. A DfSS method for the interpretation of some of the metrics used to evaluate the results of the analysis is shown in Figure 6. Analysis numbers lower than those shown in the bottom boxes give the gage a "green light".

Figure 7 shows the results of the Gage R&R in graphic output. The first graph shows the Components of Variation with the 99+% contribution in the "Part-to-Part" column. For a gage to be statistically good, the graphs starting with the one below the Components of Variation graph should be "in control", "out of control", the data points stacked on top of each other, a horizontal line, and lines that do not cross. The graphs in Figure 4 for the ALSA Gage R&R analysis fit the above criteria.

Correlation Analysis

The panels that were run on the new laser surface analyzer for the Gage R&R study were run in the same manner on the LORIA. The results of the surface analysis were used to run a correlation analysis between the new laser surface analyzer and the LORIA. The P-Value for the correlation is 0.000 and a value of 0.05 or less is considered statistically significant and well correlated. The Pearson correlation of the new laser surface analyzer and LORIA is 0.982 with a 1 being a perfect positive correlation and anything above a 0.6 being a strong positive correlation. There are three samples that show some discrepancy with the major trend. The first discrepancy is with sample 1, the glass plate. The LORIA calculates the surface smoothness of the glass around 20 while the new laser surface analyzer calculates around 4. The new system has a much higher resolution and therefore smaller deviation increments from the fitted line accounting for the lower number. On the other end of the spectrum, at sample 11, we see the new laser surface analyzer rating the panel with a higher number. Panel 11 has some glass prominence visible on the surface and the improved resolution in the new unit has accounted for it. Panel number 9 has a somewhat dull surface and the old system rates it as being less smooth than the new system. See Figure 8 for the graph of this data with 9 points plotted for each sample and for each instrument.

Orange Peel

The orange peel calculations have been re-evaluated and their resultant values are still correlated to the DuPont orange peel standard set. The 4" x 6" metal orange peel standard plaques from DuPont were analyzed. A regression analysis was run on the data available from the scans which included; line width, area under the intensity curve, range of edge of line deviation, and ALSA index. Using the values printed on the standards as the "Response" variable and the above data it was determined that the only statistically significant variable was the area under the intensity curve. Using the area under the intensity curve an equation was determined to predict the orange peel value. The algorithm used to calculate the orange peel numbers uses only the area under the Intensity curve to derive the number as it gave the highest R-Sq value of all the variables and combinations evaluated. The R-Sq value for the regression equation is 93.4%. The only problem noted so far is that a very low gloss panel will cause a false high or smooth reading from the very widely dispersed line intensity area. The resulting orange peel numbers were correlated with the numbers printed on the standards. The Pearson correlation between the DuPont standards and the calculated values is .969 with a P value of 0.000. Figure 9 shows the correlation line for the calculated points vs. the "standard" data.

Distinctness of Image

Distinctness of Image or DOI is a number form 0 to 100. A 100 is a mirror like surface, defining how clear or distinct an image appears when view as a reflection in the panel. A new method to calculate this value was developed. It utilizes the original concept, comparing the intensity of reflected line at a spectral viewing angle and the intensity of a line slightly off the spectral viewing angle, and the width of the reflected line to determine DOI. The criteria for the correlation of the calculation with the human eye evaluation was a method in which one placed a ruler at one end of the panel and viewed the reflection to determine how far the ruler could be read. The panel, ruler, and viewer were oriented at fixed positions and angles. The distance in inches that could be distinctly read from the reflected image of the ruler was used as the number to establish the relative DOI values. After evaluating all of the different variable data collected during a scan, it was determined that the spectral viewing intensity and line width were the significant variables. A regression equation was determined from the observed ruler number and its relationship with the difference in spectral viewing intensity and line width. A good statistically correlation was achieved between the observed and calculated values for DOI.

Summary

The new laser surface analyzer system retains the surface smoothness values of the old industry standard while improving speed, ease of use, and having increased capabilities for storage and retrieval of data. The current equipment used will make maintenance easier for the foreseeable future.

Figure – 1

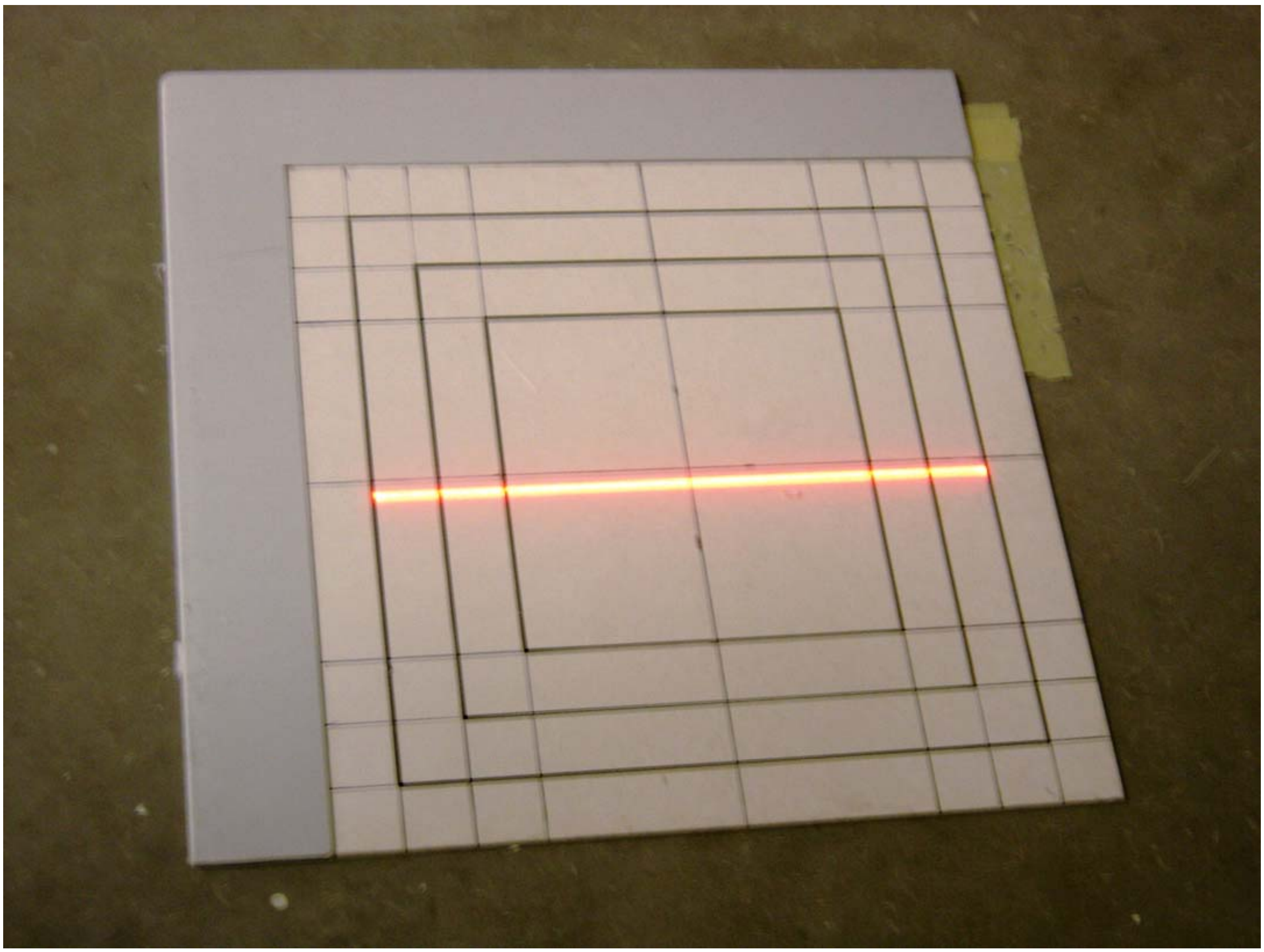


Figure – 2

Figure – 3

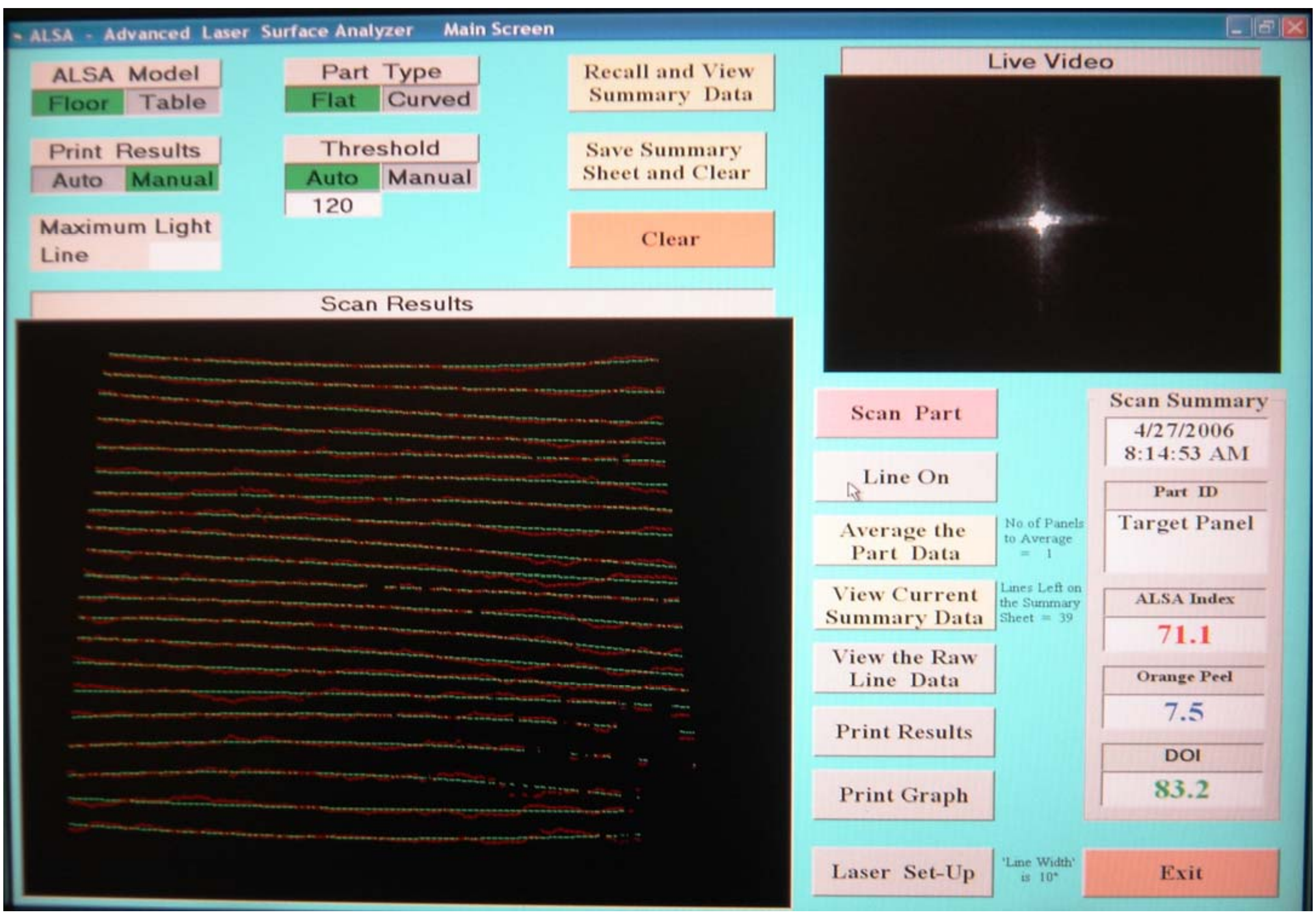


Figure – 4

Gage R&R Results		
Source	Variation Component	% Contribution (of Variation Component)
Total Gage R&R	4.48	**0.24**
Repeatability	1.08	0.06
Reproducibility	3.40	0.18
Operators	0.80	0.04
Operators*Samples	2.61	0.14
Part-To-Part	1837.68	**99.76**
Total Variation	1842.16	100.00
Number of Distinct Categories = **28**		

Figure – 5

Gage R&R Report			
		Study Variation	%Study Variation
Source	Standard Deviation (SD)	(6 * SD)	(%SV)
Total Gage R&R	2.1166	12.699	**4.93**
Repeatability	1.0373	6.224	2.42
Reproducibility	1.8449	11.07	4.3
Operators	0.8934	5.361	2.08
Operators*Samples	1.6142	9.685	3.76
Part-To-Part	42.8682	257.209	99.88
Total Variation	42.9204	257.522	100.00

Figure – 6

GR&R Metrics

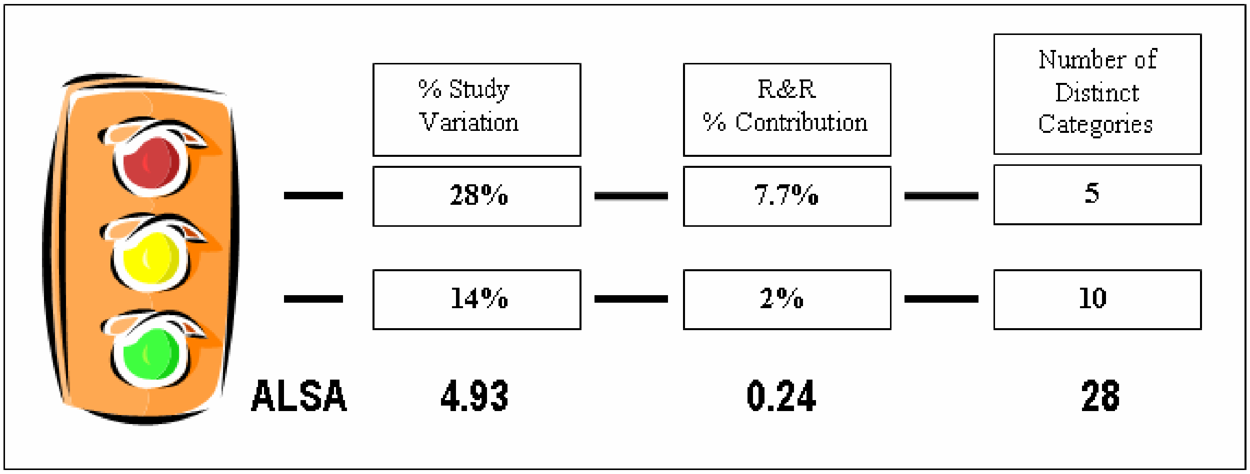


Figure – 7

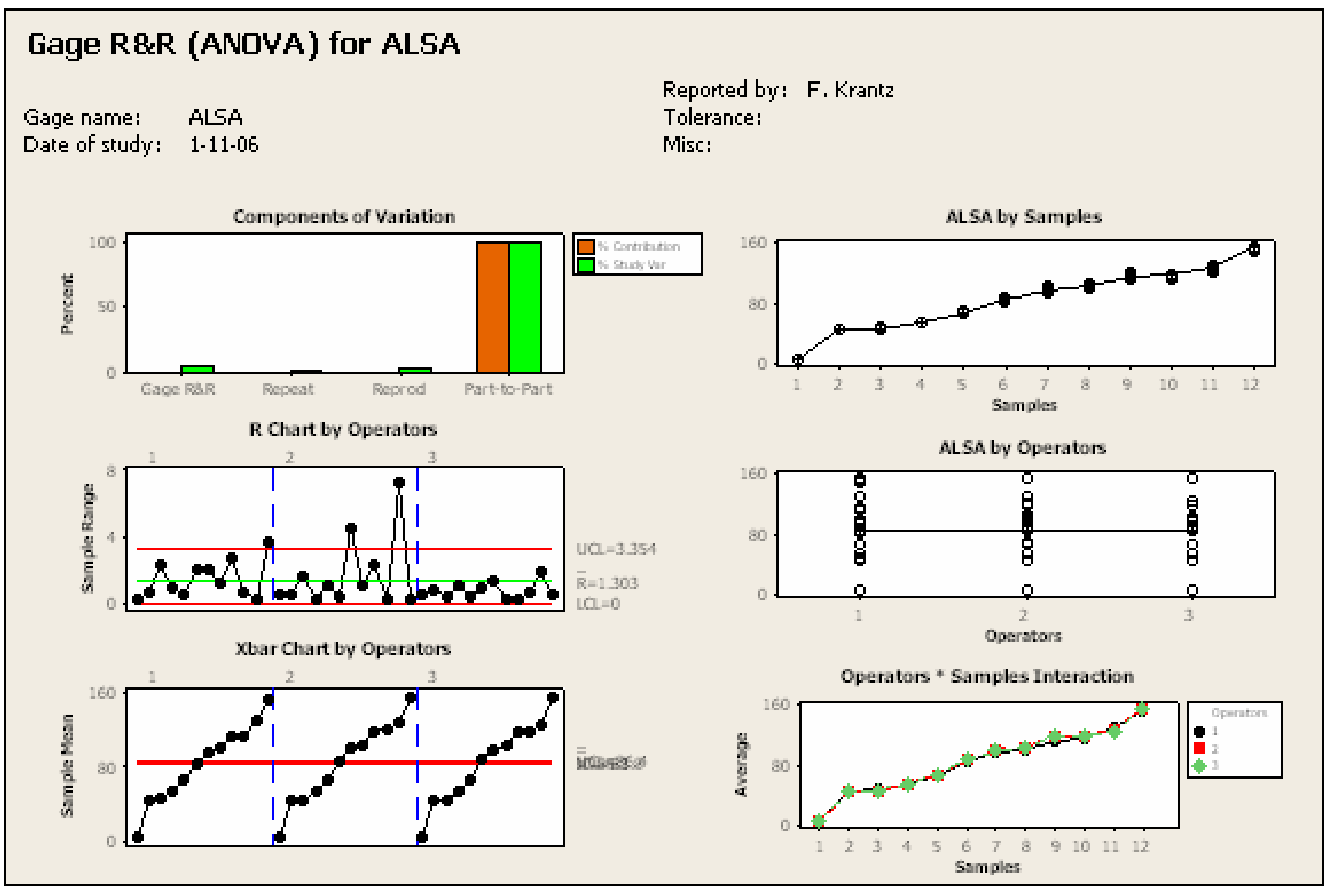


Figure – 8

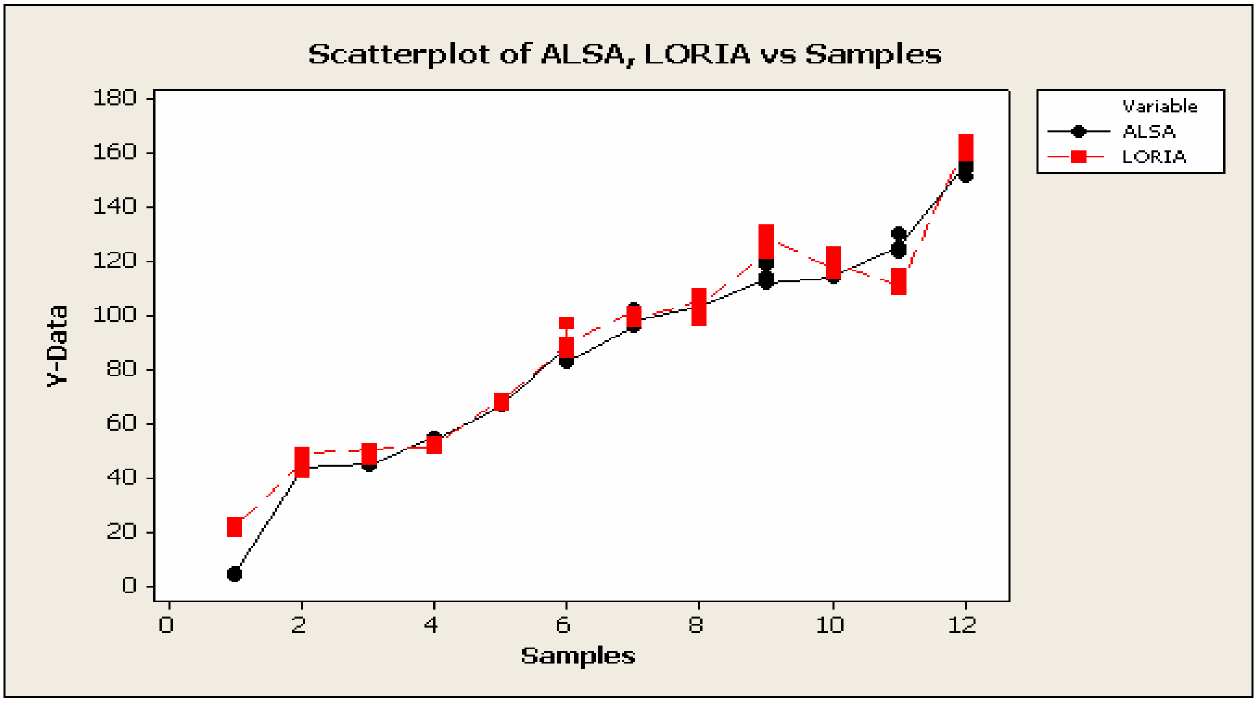
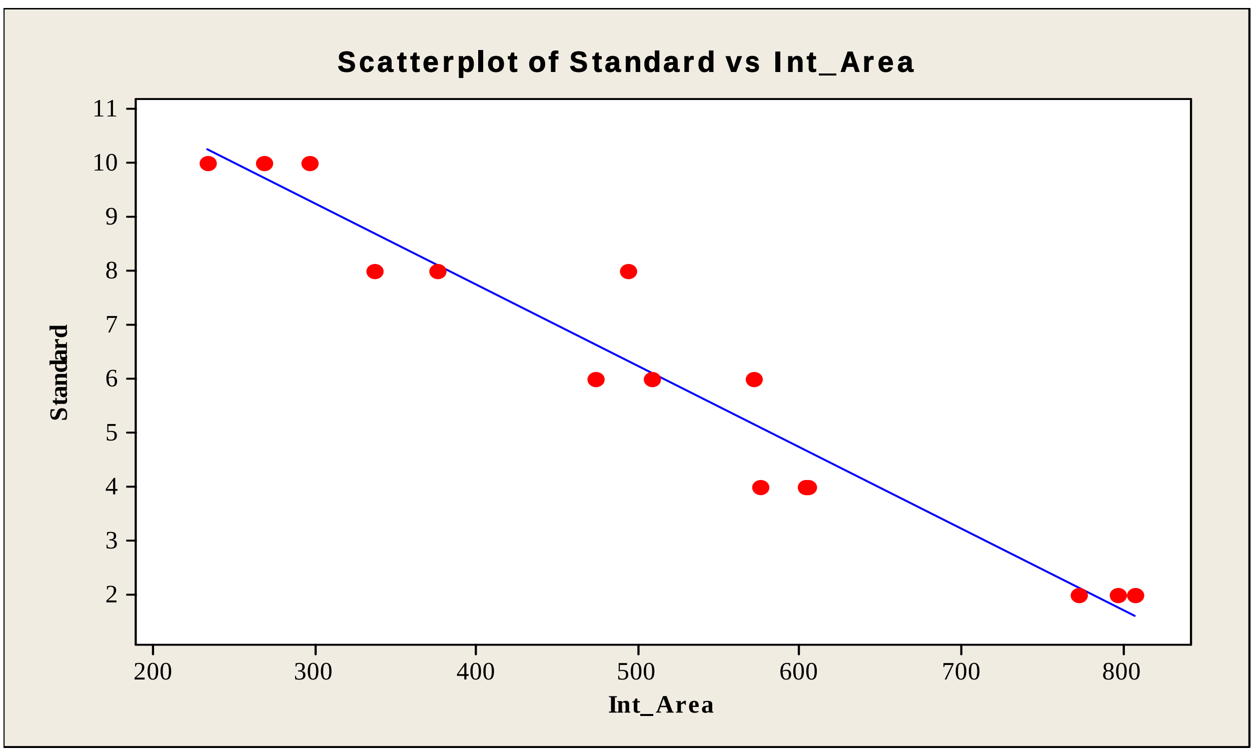


Figure – 9



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