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Stacking of Dangerous Goods in Accordance with United Nations Stacking Recommendation

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Stacking of Dangerous Goods in Accordance with United Nations Stacking Recommendation.

By

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CERTIFICATE OF APPOVAL

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M.S. DEGREE THESIS

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The M.S degree thesis of Zachary Loughery
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Master of Science Degree

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Stacking of Dangerous Goods in Accordance with United Nations Stacking Recommendation

By

Zachary Loughery

Abstract

The purpose of the study was to determine if the possible interpretations of the UN stacking recommendation could lead to different results. If this is possible the recommendation would need to be rewritten to eliminate the possibility of the same product passing or failing within the standard. The focus of this study was a plstic jerrican filled with water. The acceptable methods that are mentioned in the recommendation are the type of compression and the optional use of a fixture to simulate nesting. Each jerrican was filled in accordance with the recommendation and allowed to Condition in the testing room at 23°C and 50% humidity for at least 24 hours. The packagings were tested until an appropriate stacking load was placed on to the package. At these loads, the deflections were compared from each test set up as described by the UN recommendation. A statistical evaluation was used to compare the results from each set up with a single variable. This test showed that it was unlikely that the same deflections would occur with the different set ups and that unguided compression would have greater deflections. A long term stacking test was performed at 40°C and showed that unguided stacking test would also have a faster creep rate. The position of the package under the unguided compression was also studied. A CAD image was used to control the position of the package as it was moved to specific offsets. This showed a 1 cm offset could greatly change the deflection and that the movement on the bottom of the plate would change the angle of the swivel platen. Digital Imaging Correlation (DIC) was used to highlight the internal localized stress. These stresses were analyzed in both guided and unguided compression. The different methods will give different overall deflections at the same load.

1. INTRODUCTION

1.1. Goals & Objectives

The goal of the thesis is to determine if there is a difference in the different acceptable interpretations of the UN stacking recommendation.

The test was performed to show the deviation of the different interpretations of the UN stacking test.

1. Measure all necessary parameters and set-up/calibrate equipment.
2. Perform experiments and collect data.
3. Interpret data to experimental values
4. Perform comparative analysis of the experimental values
5. Determine sources of error and limit the impact of error in the experiment.
6. Generate the report

1.2. Background

The United Nations (UN) has set down a list of testing recommendations for the transport of dangerous goods. Dangerous goods are any substances that can cause harm to people, animals or the environment. The UN provides a list of substances that can be classified as dangerous goods [1]. These test recommendations are not always clearly written and can leave room for different interpretations. One part in particular is the stacking test described in section 6.1.5.6 of the 16th edition of the UN recommendations on the transport of dangerous goods. This method suggests using a compression tester to simulate packaging being warehoused or stored with other packagings stacked on top of it. For plastic jerricans, the is conducted run for a period of 28 days. The weight of the load should be equal to the weight of similar packagesstacked on top of the package during transport. The height, including the test sample, should not be less than 3 meters at 40^{o}C. This recommendation fails to address how the load should be applied. The type of compression being either guided, or unguided as specified in ISO 16104, and the use of a stacking fixture to simulate the lowest part of the package that would come into contact with the testing sample during stacking. This is the case with jerricans, as they are designed to interlock (nest) into each other which would not be properly simulated by a flat plate coming into contact with the package to be tested. The purpose of this experiment is to show the potential deviation of results when testing the same packagings under the different acceptable Conditions as mentioned ISO standard and the UN recommendations.

A company that is testing a product for transport may not have a mechanical compression tester.. In this case the test packaging is placed on the ground and weights are added to the top of it to simulate the stacking load. If the load tips over and the package is said to have failed the test because it was not able to support the load. A different company tests the same product using a compression tester and the package survives for the 28 days at 40°C. Another company uses a similar compression tester where a swivel platen is connected and once again the package fails to withstand the load for 28 days. What is the difference between the stated test methods? In one case there is an unguided load being stacked freely on top of a package as the package starts to yield the load shifts and cause the package to topple. A compression tester with a guided load evenly distributes the weight across the package so it just keeps getting compressed without experiencing failure. For the last case, a swivel platen is used in conjunction with the compression testers.

For this experiment packagings were subjected to a constant rate of loading for each of the acceptable methods in which a stacking load can be applied. The deflection was recorded as soon as a full stacking load was applied. These deflections were compared from different interpretations of the standard.

1.3. Literature Review

Several test standards were evaluated for the development of the experiment. The UN book of recommendations was the focus of this study and the experiment was devised to show the variation in the different interpretations of the recommendation. The amount of research pertaining to this subject in the field of dangerous goods is limited, so the packaging of retail goods was also analyzed. The biggest issue with the UN recommendation is that it fails to identify how the load should be applied; according to ISO 16104 there are three acceptable methods for applying the load to test samples.

- An unguided load on an individual packaging;
- A guided load on packaging(s);
- An unguided load on three packaging's forming one layer: Where a packaging has an inter-stacking feature the stack loading may be applied using a reproduction of the packaging base shape as the lowest component of the stack.

The ISO identify a rate of loading three types of stacking compression but doesn't make mention of a rate of loading or if a fixture to replicate interlocking features (stacking fixture) in mandatory. There are three areas of concern from the UN recommendations that were studied; the first is the type of compression being performed which can be either guided or unguided.

The second is the use of a stacking fixture to simulate the actual bottom of a package, or a pallet; and finally the rate at which the load is applied.

The paper “Importance of Compression Test Procedure for Plastic Drums for Dangerous Goods”[2] written by P. Andre, M. Veaux and J. Victor, brings up the same issue as described in this thesis. The Andrestudy focused on the use of guided and unguided compression. The findings from this study show that the transport of dangerous goods in Group One, Two and Three were not altered by the different test methods; however, there was a risk for warehousing in groups two and three and the non-guided procedure was preferred. In this study actual stacking tests were performed on different types of barrels. The tests were performed in accordance with the UN recommendations at a temperature of 40^{o}C on single packagings. Pallet quantities were also tested but these were done at room temperature. No noticeable failure was observed from these tests so the authors assumed that there is no difference in the various test methods. The test was carried out on two different types of barrels but this doesn’t show if the methods returned different values. The fact that the stacking test didn’t cause failure in the drums shows that the drums are able to pass the stacking test. Single packagings passed at 40°C and the pallet quantities passed at room temperature. However, different failure modes may be observed for different packagings under different circumstances.

One of the issues to be addressed in this study the difference between guided and unguided testing. “Analytical and Experimental Techniques for Unit Load Design” [17] by Dale Knockenmuss shows how the stacking strength is affected by horizontal forces along with vertical forces and failure can occur in both the vertical and horizontal direction. A guided compression test will not load the package horizontally. All the force is applied in a vertical direction and will compress the package evenly. Unguided compression is allowed to move about a point or a plane. These extra degrees of freedom for the plates will apply forces in the horizontal direction. If failure in the horizontal direction is a concern then unguided compression is necessary.

Luther “Chip” Stone has brought up the issue of fixed vs. floating vs. swivel platen, in his paper “Compression testing: fixed vs floating platen.”[23] the same terminology was used in the paper. A fixed platen is a guided platen that will remain flat during compression because it is held such that no rotation can occur. The platen remains parallel to the other platen during compression. Using a fixed platen is a type of guided compression test. Stone also mentions two types of plates that are used during unguided compression; a swivel platen is the more common type of unguided plate. A swivel platen is held at the center with a ball and socket type joint to allow free rotation. As the plate tilts, it adds a horizontal force on to the package; also the plate will have some horizontal movement. This movement is dependent on the offset of the pivot point to the platen.

A true floating plate will not add additional horizontal force to the platen as shown in "Analytical and Experimental Techniques for Unit Load Design"[17] by Dale Knockenmuss, the compression in this study uses a true floating platen. Other important items from this paper are how Knockenmuss addresses the failure modes from vertical and horizontal forces. The section 6.1.5.6.3 of the UN recommendations states the criterion for passing a test as the following; "No test sample may leak. In composite packagings or combination packagings, there shall be no leakage of the filling substances from the inner receptacle or inner packaging. No test sample may show any deterioration which could adversely affect transport safety or any distortion liable to reduce its strength or cause instability in stacks of packagings. Plastics packagings shall be cooled to ambient temperature before assessment."[1] This means that failure is subjective but can come from vertical displacement as well as horizontal displacement. This failure can be caused by the bottom layer of packaging shifting such that the entire stack is compromised, as was this case with Knockenmuss findings.

Often, products are made with certain design type features to improve the functionality. The jerricans used in the study are blown molded in way that allows them to interlock when stacked. Also, a handle is placed about the filling spout to allow for carrying and the needed space for stacking is removed from the bottom. A design feature can affect overall strength demonstrated in. "Effect of Carrying Slots on the Compressive Strength of Corrugated Board Panel"[13]. This study shows the reduction in overall compression strength when the area is reduced, which is relevant under two different types of circumstances. One is reduction when the load bearing area is changed; such as the importance of a stacking fixture for usage of nesting products. The other circumstance is when stresses are localized about a point, such as a handle. These stresses can change position dependent on the shifting in the swivel platen. This is relevant when tests are compared from guided and unguided compression tests.

The International Safe Transit Association ISTA 3J as well as the Series 6 Sam's Club require a pallet be placed on top of a pallet load before compression is performed. This simulates the real world stacking of products. “Sam’s Club Distribution Testing Success”[15] notes that these are the only test protocols that require the use of a pallet to simulate actual loading. This stacking fixture is only referenced to being permissible in both the ISO 16104 and the UN recommendations. The ISTA 3J describes how a pallet should be placed on top of unit loads to simulating compression. This demonstrates the importance of the use of a stacking fixture.

The stacking test is carried out over an extended period of time. For metal containers the loading time is 24 hours. For plastic and composite packagings the load needs to be applied for 28 days at 40°C. This will cause the packagings to creep. The phenomenon of creep in high density polyethylene (HDPE) needs to be better understood. A stacking test is unpredictable and difficult to control, a compression test is better controlled and then understanding how the package will “creep” can be used to determine the end result. For the purpose of this experiment, a statistically significant sample could not have been produce in the time period. However the initial loadings of the packagings could be determined accurately and repeatedly from the “apply and release” method of a compression machine. The creep behavior will be approximated to demonstrate the differences that occur from the different types of loadings and how they affect the end results. “Compressive strength and creep of recycled HDPE used to manufacture polymeric piling” [9]shows that with a higher strain rate the rate of creep will also increase for recycled HDPE. Thusly the higher initial deflection that occurs after loading will result in a more rapid creep. “Influence of Normal Stress on Creep in Tension and Compression of Polyethylene and Rigid Polyvinyl Chloride Copolymer”[21], additionally developed an equation for determining the creep rate in HDPE. Again showing that at higher strains the rate of creep is greater.

2. BASICS

2.1. Samples studied

The jerrican used for testing had a nominal volume of 22 l as shown in Figure 1, from Mauser-Werke GmbH. Each sample was filled with 24.24 liters of water as the 98% brimful capacity as calculated by ISO 16104. [5] and in accordance with standard procedure at Bundersanstalt für Materialforschung und-prüfung.

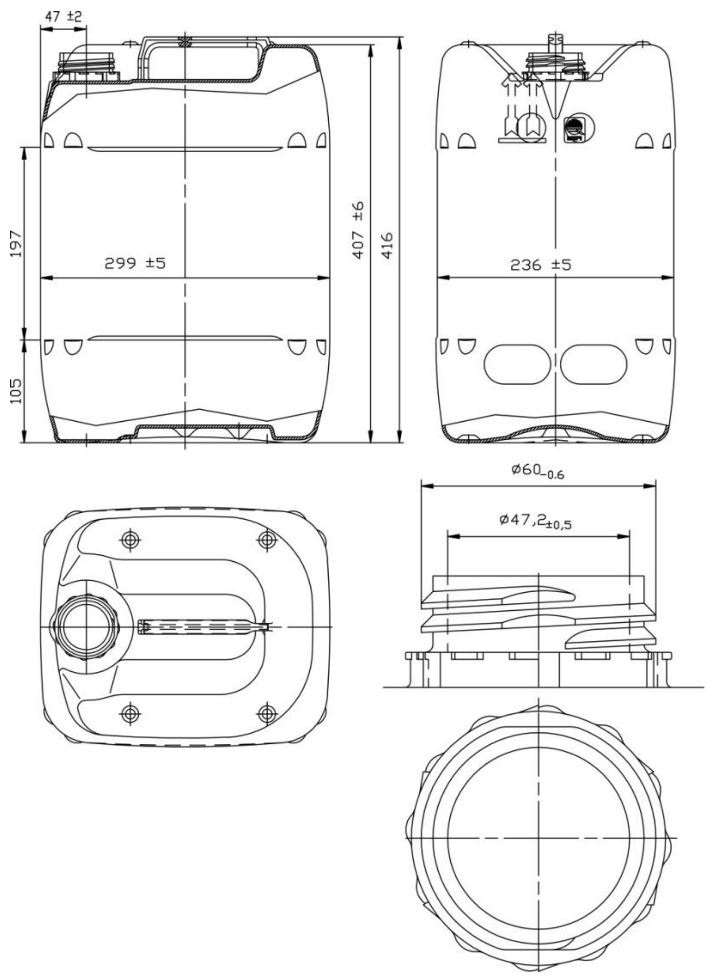

Figure 1: Drawing of the jerrican with a volume of 22 l, Mauser-Werke GmbH

2.2. Related theory

This section described the basic mechanical principles that in this document to support concepts or results.

2.2.1. Hooks Law

Hooks law is the stress strain relationship that within the plastic region of deformation there is an equal relationship to the amount of deformation to the amount of force applied. This principle was used to show the difference between the test methods. The force was recorded as the reaction through the package.

2.2.2. Creep

The Society of Plastic Engineers defines creep as “the tendency of a solid material to slowly move or deform permanently under the influence of stress that below the yield strength of the material.” They also identify of how this will be more served with higher stresses and elevated temperatures. The UN stacking recommendation is to be performed under a load at 40^{o}C for a duration of either 24 hour or 28 days depending on the type of package.

2.2.3. Mann-Whitney U test

The Mann-Whitney U test is a statistical test that analyzes the medians of a data set instead of the means so it can be used for non-parametric data. Histograms of all data sets were found to not have a normal distribution. In this case the Mann-Whitney U test is needed to test the significance of 2 independent sample sets. It studies the sample of the data to determine if the data could be in the same population. This would be that the results should be same. The values are rewritten in ascending order and given a rank. Equal or tied values are adjusted. The two tailed test means the results were compared to find if they were not equal.

2.2.4. Strain gauges and Load Cells

A strain gauge is generally made from a wire and uses the principle of resistivity to determine deformation. Given that resistivity is a function of the material’s length and area, as these factors change, so does the amount of resistance that the wire has. As a strain gage is compressed the length decreases and the area increases causing a decrease in the resistance, this drop can be used to determine the amount of deflection. The Tekscan pressure mat uses a lattice of strain gages to determine the pressure at a given point.. A load cells works similarly to a strain gauge in which force is transformed into an electrical signal. The load cells used with strain load cells with also use the deformation of the material and resistivity to find

3. DESCRIPTION OF TEST

3.1. Equipment Used

3.1.1. Compression tester

Custom built compression tester with four screws in each corner and 10kN load capacity calibrated in 2012. This was used for all dynamic compression including fixed and floating platen. The machine ran with Instron Blue Hill software version 6. This is able to control the rate the load was being applied and record all load and deflection data.

3.1.2. Static stacking machines

Stacking cylinders were used to apply a constant load to packaging. Calibrated cylinders at which a load was set and applied to the packaging. These cylinders were not able to record the deflection of the package.

3.1.3. Tek Pressure mat

Map and Sensor Model 3150 with I-scan light software. The software was able to playback of the force distribution.

3.1.4. Floor scale

Satorius Is300IGG-S floor scale.

3.1.5. Lab view

National Instruments LabVIEW was used to make custom programs to measure the pressure. These programs were already in use a BAM

3.2. Methodology

This section describes the method used to determine results. For this study all jerricans were filled with water to 98% brimful capacity as determined in accordance with ISO 16104. The research was broken up into different tests. A dynamic stacking test (compression) was performed to accurately apply a load. Samples were allowed to Condition for a period of at least 24 hours in a controlled room set to 23°C and 50% humidity. All samples were placed into a compression machine and compressed to 50% of the original height. This test was performed with different set ups as suggested in the UN recommendation. Three stacking loads were calculated in accordance with ISO 16104 and the UN recommendation. The deflections at these three loads were statically analyzed for comparison. All samples were also place on top of a pressure mat which was used along with a screen capture device to record the force distribution of bottom of the jerrican during compression. A static stacking test was performed to determine the rate of creep in the jerrican. Samples were placed under the highest stacking load calculated and the lowest height as required by the UN. Both guided and unguided stacking tests were done while measuring the deflection from each corner. These samples were allowed to Condition for a period of 48 hours at 40°C. These tests were performed at the same Conditions. To determine the resultant force that was caused by the use of the swivel platen a pressure test was performed along with measuring the angle that the swivel platen made. This angle was used in the calculation of the resultant force that would be applied to the package. Digital Imaging Correlation was used on 3 samples to show the localized stresses from in jerrican.

3.2.1. Dynamic Compression Test

To evaluate the relationship of different interpretations of the stacking test a compression test was used with the following method.

80 jerricans were filled with water in accordance with ISO 16104 and compressed to 50% of the original height original height, or until the package could no longer be compressed. ISO 12048 suggests a speed of 10 mm/min. ASTM D642 uses a compression rate of 12.7 mm/min in order to show the affects of different rates half and double of the suggested speed will be used (5 mm/min and 20 mm/min) respectively. Three different rates were initially selected at 5 mm/min, 10 mm/min and 20 mm/min. After testing at 5 mm/min and 20 mm/min it was determined that 10 mm/min was not necessary. The load versus deflection will be recorded from the compression’s machine software. The pressure will be mapped from a strain gauge mat; these values will be used for comparison for each of the other Conditions as shown in the Table below.

Fixed/Guided Compression		
Rate	Plate to Plate	Stacking Simulation
5mm/min	Condition 1	Condition 4
20mm/min	Condition 3	Condition 6
Swivel Platen/Unguided Compression		
Rate	Plate to Plate	Stacking Simulation
5mm/min	Condition 7	Condition 10
20mm/min	Condition 9	Condition 12

Table 1: Testing Conditions used

The stacking simulation indicates that a fixture will be used to simulate the bottom of a jerrican pressing onto the top instead of the flat compression plate. This was made by filling the lower section of a jerrican with epoxy to create a ridge fixture. 10 samples were tested in each Condition. 3 stacking loads were calculated and the deflection at these loads where used for the comparison. The average deflection at each load for all 80 samples was compared to the average deflection of the 10 samples for a specific test.

Figure 2: Stacking Fixture

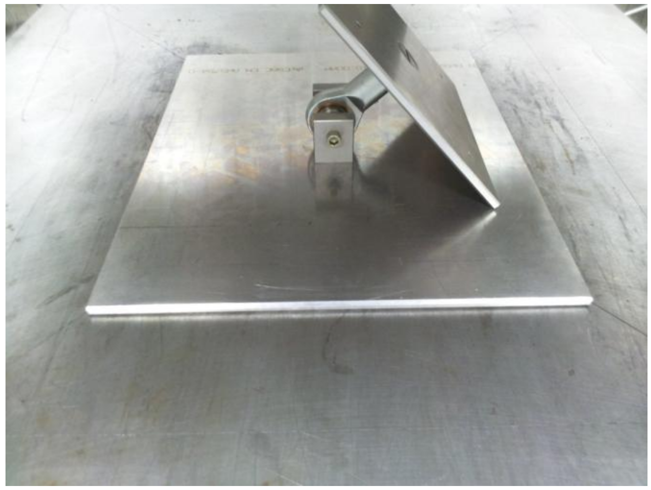

Figure 3: Swivel

3.2.2. Static Stacking test

A stacking test was done to determine the different rates that the jerrican would creep and if there is a difference depending on the strain rate as shown in the paper by compressive creep in HDPE [7]. A total of 4 samples were tested in a guided and unguided stacking machine at the low load and high load. I (?) sample each. This test was performed for an extended period of time. The deflection was measured at each corner of the compressive plate and the average deflection was plotted against time.

Figure 4: Stactic Stacking Machine

3.2.3. Resultant Force

The horizontal component needed to be calculated in order to determine if there was a significant difference in the resultant load, and the load as found by the compression machine. Seven samples were used at the two different speeds; the stacking fixture was used to help position the samples. The angle was measured and recorded at 10 mm increments. A third order polynomial was used to fit the trend of the line as shown in Figure 4. This equation was used to determine the angle at any deflection. The angle as found by the equation was used to calculate the resultant force for the unguided compression tests.

Figure 5: Digital Level

.

3.2.4. Pressure Test

Jerricans were filled with water to 98% brim full capacity. Two samples were tested with Condition 3, (20 mm/min, guided compression, and no stacking fixture,) two were tested with Condition 9 (20 mm/min, unguided compression and no stacking fixture) and two samples were tested with Condition 1 (5 mm/min guided compression and no stacking fixture). A pressure valve was placed into the side of the jerrican to measure the internal pressure of the package during loading. From this test it was found that the pressure remained almost the same in both tests even though the compression tester records a lower load on the swivel platen than on the fixed platen. The load vs. deflection graphs were plotted with the pressures as shown in Figures 17-19. From this test it was determined that the resultant forces were equal however the compression tester can only record the vertical component of the force.

Figure 6: Jerrican with Pressure Valve

3.2.5. Digital Imaging Correlation (DIC)

To determine where the local stresses occur within the jerrican, a digital imaging correlation (DIC) test was performed. DIC is able to measure the local deformation by using “stereo photogrammetry” with two cameras. The sample area was painted with an antireflective coating and then a spray was used to create a pattern on the surface where sub-images called facets could be tracked. The second camera allows for tracking in all three dimensions. The strain and displacement parameters for each test are shown below.

Information for Measuring			
	Front	**Guided**	**Unguided**
Size of facets (x,y)	18 x 18 Pixel	18 x 18 Pixel	18 x 18 Pixel
Distance between facets (x,y)	11 x 11 Pixel	12 x 12 Pixel	12 x 12 Pixel
Number of facets (x,y)	136 x 102	124 x 92	124 x 91
Picture width and height	1624 x 1236 Pixel	1624 x 1236 Pixel	1624 x 1236 Pixel
Temperature	23°C	23°C	23°C
Measuring volume	135mm x 103 mm x 82 mm	135mm x 103 mm x 82 mm	135mm x 103 mm x 82mm
Objective	35mm	35mm	35mm
Measured specimen area	125mm x 100 mm	125 mm x 90 mm	125mm x 100 mm

Table 2: Digital Imaging Parameteres

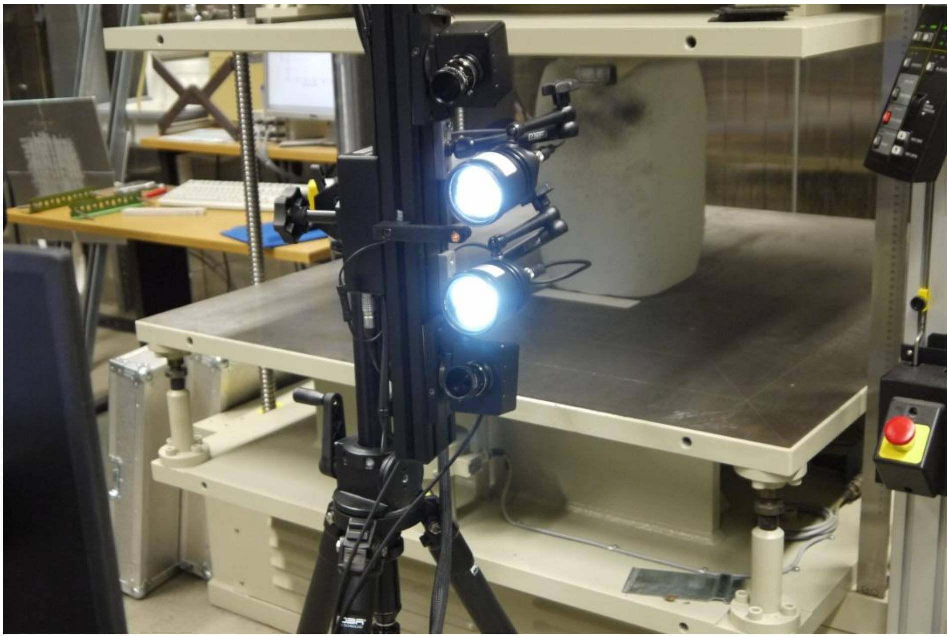

Figure 7: Digital Imaging Set Up

3.2.6. Positional Study Using a Compression Machine

The position of the jerrican in relationship to the swivel platen was studied to determine how the forces act when the package is shifted out from center to a controlled offset position. This was done using a large plotter to print a scale bottom view of a Computer Aided Drawing (CAD) model of a jerrican. This printing was cut to the size of the plate and placed over the swivel platen. The stacking fixture was then aligned to the CAD drawing. A total of eleven printings were created as shown in Figure 8 and at the center position with offset angles of 30 degrees and 60 degrees.

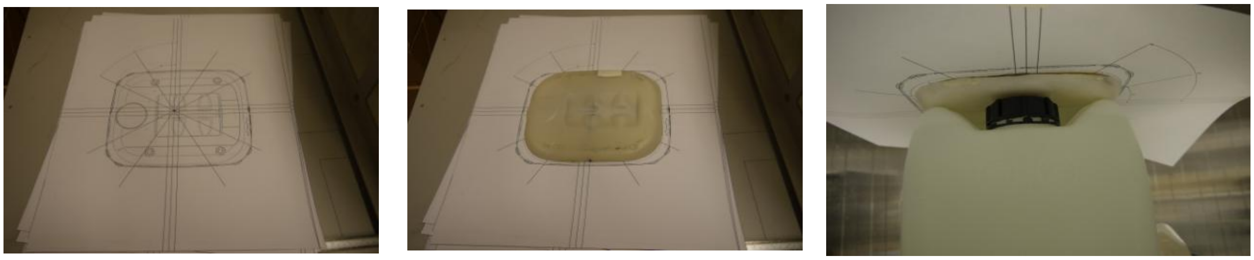

Figure 8: Positional Setup

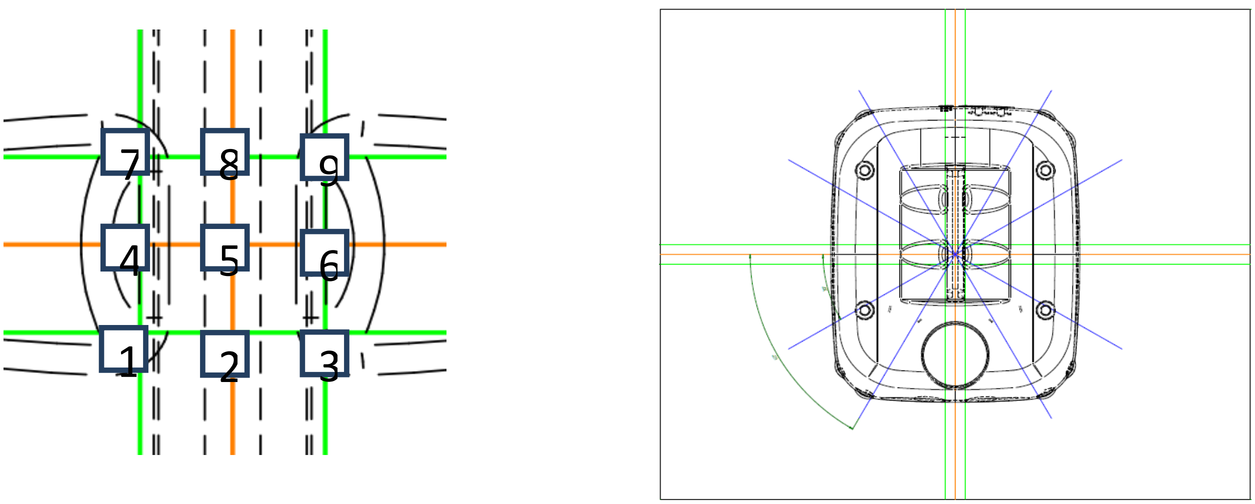

Figure 9: Positions 1-9, 1 cm distance between positions and Image of the bottom of the can with center lines

4. DATA ACQUISITION AND ANALYSIS

4.1. Data Analysis

4.1.1. Variable Identification

Variable	Definition	Units
H	Relevant stacking height of Packagings	millimeters (mm)
h	Height of package	millimeters (mm)
C	Volume of water	Liters (L)
d	Density of Transported Substance	kilograms per Liter (kg/L)
d.water	Density of water	kilograms per Liter (kg/L)
d.nitricacid	Density of nitric acid	kilograms per Liter (kg/L)
m	mass of the empty package and components	kilograms (kg)
θ	Angle of rotation	degrees (deg)
M.1	Minimum stacking load	Kilonewtons (kN)
M.water	Stacking loads for 3-5 meters of water	Kilonewtons (kN)
M.nitricacid	Stacking loads for 3-5 meters of nitric acid	Kilonewtons (kN)
Load.max	Maximum load of evaluation	Kilonewtons (kN)
Load.min	Minimum load	Kilonewtons (kN)
Load.med	Median Load	Kilonewtons (kN)
Length.1	Length of pivot point to plate	millimeters (mm)
Fy	Vertical compression force	Kilonewtons (kN)
Ffx	Horizontal force from friction	Kilonewtons (kN)
Ry	Vertical reaction force	Kilonewtons (kN)
Rx	Horizontal reaction force	Kilonewtons (kN)

Table 3: Variable Identifaction

4.1.2. Calculations

The stacking loads were found from the following equation as per ISO 16104 sections 5.3.2.2

$M_1 = ((H/h) – 1)(C.d.n+m)$

The minimum Stacking load was found to be the following,

$$M_1 := \left[\left(\frac{H}{h}\right) - 1\right](C \cdot d_{water} + m) \rightarrow \left(\frac{3000\,mm}{416\,mm} - 1\right) \cdot \left(24.25L \cdot 1 \cdot \frac{kg}{L} + kg\right) = 156.841kg$$

The force due to loading was found by multiplying the stacking load by acceleration due to gravity, per below: $M_1 \cdot g$

$$156.841kg \cdot 9.807\frac{m}{s^2} = 1.538kN$$

The number of jerricans required to meet the minimum height requirement was found according to the following calculation:

$$\frac{H}{h} \rightarrow \frac{3000\,mm}{416\,mm} = 7.212$$

The number of jerricans that could occur in the stack was determined to be 7.2-12 cans. For evaluation purposes the height of the stacks is as follows

$$N := \begin{pmatrix} \frac{H}{h} \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} \rightarrow \begin{pmatrix} \frac{3000\,mm}{416\,mm} \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} = \begin{pmatrix} 7.212 \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} \qquad H_1 := N \cdot h \rightarrow \begin{pmatrix} 7.212 \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} \cdot 416\,mm = \begin{pmatrix} 3 \\ 3.328 \\ 3.744 \\ 4.16 \\ 4.992 \end{pmatrix} m$$

The maximum height for evaluation was 5 meters, and even though these specific jerricans do not fit perfectly between 3 to 5 meters, this recommendation applies to all packagings that can be subject to the stacking test.

The stacking loads from the previous heights of jerricans were found to do the following

$$M_{water} := \left[\left(\frac{H_1}{h}\right) - 1\right](C \cdot d_{water} + m) \cdot g \rightarrow \left(\frac{H_1}{416\,mm} - 1\right) \cdot \left(24.25L \cdot 1 \cdot \frac{kg}{L} + kg\right) \cdot 9.807\frac{m}{s^2} = \begin{pmatrix} 1.538 \\ 1.733 \\ 1.981 \\ 2.229 \\ 2.724 \end{pmatrix} kN$$

The density of nitric acid was also used for evaluation to determine the maximum loading that may occur.

$$M_{nitricacid} := \left[\left(\frac{H_1}{h}\right) - 1\right]\left(C \cdot d_{nitricacid} + m\right)\cdot g \rightarrow \left(\frac{H_1}{416\,mm} - 1\right)\cdot\left(24.25L\cdot 1.42\frac{kg}{L} + kg\right)\cdot 9.807\frac{m}{s^2} = \begin{pmatrix} 2.159 \\ 2.433 \\ 2.78 \\ 3.128 \\ 3.823 \end{pmatrix}\cdot kN$$

The maximum load to be used in the evaluation would occur with a 5 meter stack filled with nitric acid is as follows:

$$M_{nitricacid_4} = 3.823kN$$

A third point was chosen as the median of the high and low value and was found as the mean of the high and low value

$$Load_{med} := \frac{Load_{max} + Load_{min}}{2} \qquad \frac{3.823kN + 1.538kN}{2} = 2.68kN$$

For each of these three loads the corresponding deflections were found.

To determine the resultant force the angle of the plate was recorded. A third order polynomial was fit to the data plot and the equation was found to be.

$$Angle = .0002x^3 - .0149x^2 + .1949x$$

Given the average deflections for testing Condition 10 the angles were found to be

$$\theta_{10} := .0002x_{10}^3 - .0149x_{10}^2 + .1949x_{10} \text{ explicit}, x_{10} \rightarrow .0002\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix}^3 - .0149\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix}^2 + .1949\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix} = \begin{pmatrix} 0.562 \\ -2.521 \\ -3.275 \end{pmatrix}$$

This equation was used to determine the resultant force that was on the package

$$Resultant = \sqrt{\sin(\theta_x)\,Load_{Instron}^2 + Load_{Instron}^2}$$

The maximum difference would come from the highest angle

$$\sqrt{\left(\sin\left(\theta_{10_2}\,\mathrm{deg}\right)\cdot \mathrm{Load}_{max}\right)^2 + \mathrm{Load}_{max}^{\;2}} = 3.829\mathrm{kN}$$

A phenomenon that is described in this paper as "lateral shift" can be defined by the following equation. Below are shown the resulting lateral shifts from 1 degree to 9 degrees for the plate that was used.

$$\mathrm{Lenght}_1 := 37\mathrm{mm} \qquad \theta := \begin{pmatrix} 1 \\ 3 \\ 5 \\ 7 \\ 9 \end{pmatrix}\mathrm{deg} \qquad \mathrm{Lenght}_1\cdot\tan(\theta) = \begin{pmatrix} 0.646 \\ 1.939 \\ 3.237 \\ 4.543 \\ 5.86 \end{pmatrix}\cdot\mathrm{mm}$$

4.2. Data Products

4.2.1. Graphs

4.2.1.1. Histogram

The histograms below show that not enough samples were collected to prove that data would be normally distributed as is required by the T test. Since the data is impartial we would expect normally distributed data, in which case the T test could be used. A Mann-Whitney U test was used since the data did not follow a normal distribution. These values were used for the assessment of the results to determine if the test would yield the same results.

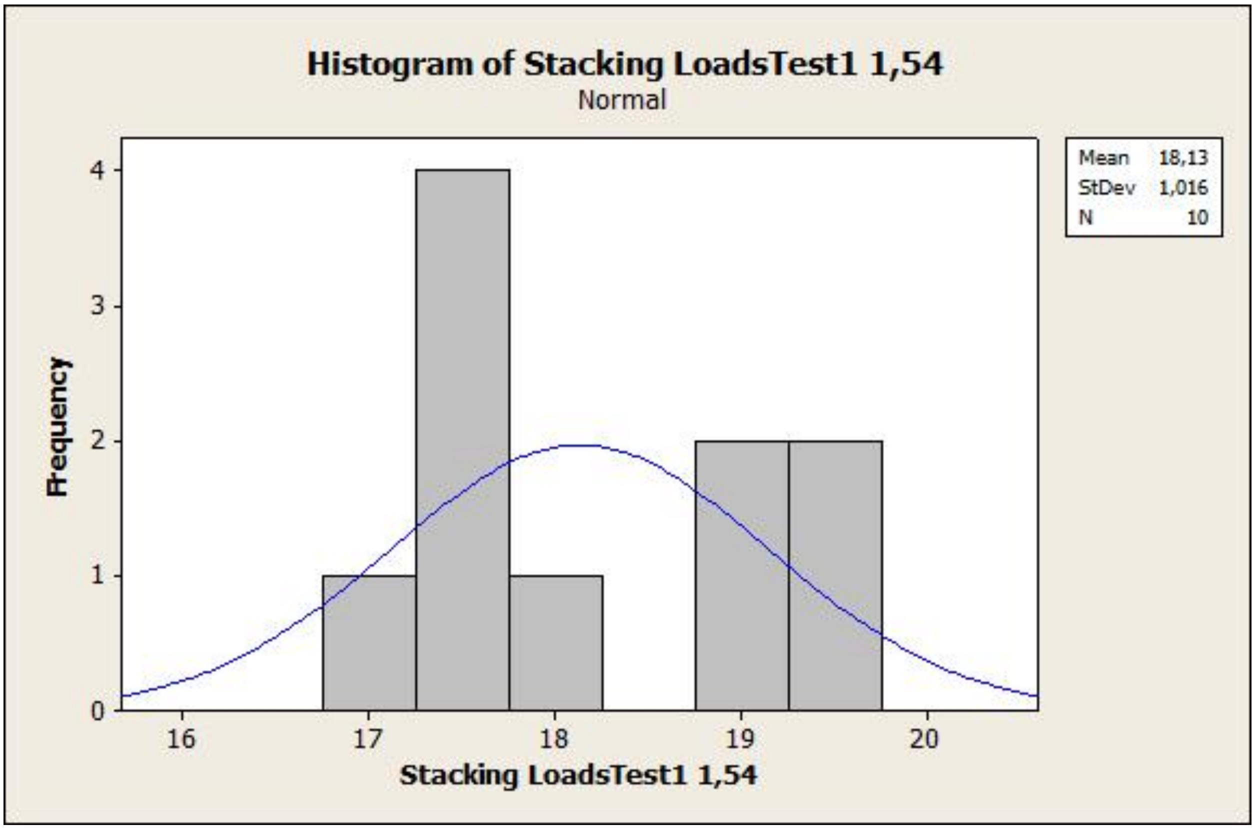

Figure 10: Sample Histogram

The deflection at each stacking load was compared to the overall average deflection from every test.

4.2.2. Tables

4.2.2.1. Average deflection at Stacking Loads

Stacking Load (kN)	Sample	Deflection (mm)	Average Deflection (mm)	Difference from Average
1.54 kN	Condition 1	17.98	13.73	4.25
	Condition 3	18.03		4.31
	Condition 4	12.86		-0.87
	Condition 6	9.47		-4.26
	Condition 7	19.4		5.67
	Condition 9	16.13		2.40
	Condition 10	11.68		-2.05
	Condition 12	9.93		-3.80
2.68 kN	Condition 1	24.92	22.95	1.97
	Condition 3	23.73		0.78
	Condition 4	22.75		-0.20
	Condition 6	17.53		-5.42
	Condition 7	26.29		3.34
	Condition 9	22.24		-0.71
	Condition 10	32.37		9.42
	Condition 12	16.93		-6.02
3.83 kN	Condition 1	37.45	36.87	0.58
	Condition 3	34.43		-2.43
	Condition 4	38.4		1.53
	Condition 6	32.87		-4.00
	Condition 7	39.97		3.10
	Condition 9	36.38		-0.49
	Condition 10	41.18		4.31
	Condition 12	37.37		0.50

Table 4: Average Deflections at Stacking Loads

4.2.2.2. Positional study

Positional study deflections at Stacking Loads			
	Minium Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
1	7.67	30.00	38.00
2	9.00	30.33	38.33
3	8.67	30.33	37.67
4	9.00	17.00	36.00
5	9.67	16.00	37.00
6	10.00	17.00	36.67
7	9.33	19.00	34.67
8	9.33	15.67	32.67
9	10.67	19.33	33.33
30	7.67	17.33	40.00
60	9.00	17.33	39.33
	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	10.67	30.33	40.00
Average	9.09	20.85	36.70
Minimum	7.67	15.67	32.67
Range	3.00	14.67	7.33
Standard Deviation	0.90	6.12	2.35

Table 5: Positional Deflections

5. DISCUSSION OF RESULTS

5.1. Overall Concerns

Filling the jerricans to 100% brim full capacity requires that they be tilted; this is not representative of an actually filling process. Section 4.3.3.1 of ISO 16104 says that “no steps should be taken, by tilting in order to allow water to flow into designed features above the closures”. Standard operating procedure at Bundersanstalt für Materialforschung und-Prüfung is to tilt the package. For experimental purposes and to create a worst case scenario the jerricans were tilted during the filling process resulting in the 98% brim full capacity to be 24.24 liters.

The position of the jerrican in the compression tester is critical, any movement off center will change how the swivel platen shirts and settles into a position. The greatest error was found in Sample 10, in which it was very difficult to control the center position of the jerrican. To better understand this process a positional study was developed to show the effects of moving the package out from the perfect center of the swivel platen. This test is further described in Section 5.7. The pressure mat was used to show how the jerrican would respond to the force from the different types of compression. It was desired to export the load variance over time data for each cell to understand how the force is translated through the package. The limitations of the software and equipment made this impossible. Another limit of the software was the inability to record videos of the pressure mat as a load is applied. A screen capture program was used to record the videos. The pressure mat is able to interpret the area by the number of activated cells and determines the load by the collective resistance that is in each cell, in order to make an appropriate calibration an actual jerrican needs to use. Initially calibration was performed by using a large rigid plate to which a load was applied and calibrated. A calibration also needs to run at the maximum load so the software can set the appropriate scale. This also leads to an issue in which the mat interpolates all other loads, when there may not be a linear relationship. After multiple uses the mat became damaged, and some of the cells no longer read. This voids the initial calibration file because cells that were receiving a load are no longer able to read, so the overall load will be lower than what is read from the compression machine. Other failures included a slight fold in the mat that would cause a row cell to all be activated. The initial testing shows that the mat is an excellent tool for the visual comparison, but the load is more accurately read from the load cells from the compression machine. Because of these limitations and errors it would be impossible to compare the results of the pressure mat from one sample to another as accurately as the values from the load cells on the compression machine. Another attempt at calibrating the mat for use was done by filling a jerrican with sand.

The first set of experiments were run at the slow speed of 5 mm/min. This was done so that the product would not receive any shock from the weight being loaded. After all four testing Conditions were run at 5 mm/min there was sufficient evidence that the different configurations of the testing Conditions would affect the results. To determine if the rate of dynamic loading had any effect on the initial deflection the 20 mm/min rate was run next. After completing testing Conditions 7,9,10 and 12 it was found that the compression rate did make a difference to the deflections at the different stacking loads. However this difference wasn’t significant to test the middle range of 10 mm/min as initially thought.

The compression machine used for the dynamic stacking test has a total of three loads cells on the underside of the bottom compression plate. These load cells captured the vertical force that is applied as a reaction from the package being tested. As the unguided compression starts to rotate the vertical component of the resultant force is measured. This will be an issue for any person using a load cell to capture data with a swivel platen because the horizontal component or components will be lost. This results in a higher load being applied to the package when there is any rotation in the swivel platen and a horizontal load is applied. Evidence from the pressure tests that were performed shows that the same pressure was found in both the unguided and guided compression. The pressure is equal to the force divided by the area. The area is the area of the valve and since the same valve was used in each sample the force is also the same. It was found that the resultant force was under 6N and could be ignored. Also the horizontal components will not contribute to vertical deflections unless the package began to buckle. Given the short rigid structure it is unlikely that any buckling took place and the horizontal components could be neglected, and only the vertical components were used to calculate the deflection.

5.2. Dynamic Stacking Test

5.2.1. Condition 1, 5mm/min, Guided Compression, and no Stacking fixture

Condition 1 was performed at the slow speed of 5 mm/min, guided compression and no stacking fixture. The Table below shows a summary of the results of the deflections at the selected stacking loads for all 10 samples.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	19.584 mm	26.167 mm	38.500 mm
Average	17.983 mm	24.917 mm	37.450 mm
Minimum	16.833 mm	23.583 mm	35.334 mm
Range	2.751 mm	2.584 mm	3.167 mm
Standard Deviation	0.998 mm	0.945 mm	1.014 mm

Table 6: Condition 1 Summary

The average deflections from test Condition 1 were compared to the average deflections from all 80 samples. Table 7 shows the average deflections from all Conditions and the average deflections of Condition 1. Condition 1 resulted in higher deflections at every stacking load; with a convergence as it approached higher loads.

Loads	All tests average	Condition 1	Difference
1.54 kN	14.43 mm	17.98 mm	-3.55 mm
2.68 kN	23.37 mm	24.92 mm	-1.55 mm
3.83 kN	37.26 mm	37.45 mm	-0.19 mm

Table 7: Conditional 1 compared to all tests

5.2.2. Condition 3, 20 mm/min, Guided Compression, no Stacking Fixture

Condition 3 was performed at the fast speed of 20 mm/min using guided compression and no stacking fixture. Below is a Table of the summary of the ten samples.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	18.334 mm	24.000 mm	36.000 mm
Average	18.033 mm	23.733 mm	34.433 mm
Minimum	17.667 mm	23.333 mm	33.000 mm
Range	0.667 mm	0.667 mm	3.000 mm
Standard Deviation	0.292 mm	0.211 mm	0.982 mm

Table 8: Condition 3 summary

Loads	All tests average	Condition 3	Difference
1.54 kN	14.43 mm	18.03 mm	-3.60 mm
2.68 kN	23.37 mm	23.73 mm	-0.37 mm
3.83 kN	37.26 mm	34.43 mm	2.82 mm

Table 9: Condition 3 compared to all tests

As shown in Table 9 the average deflections of Condition 3 were greater at the low and median load. However the deflection was significantly lower at that maximum loading value. It’s important to notice the rate of change that applies to Condition 3. The deflections start out much higher than the average from all testing Conditions and then fall much lower at high loads. The standard deviation also increased at the higher loads showing that the deflection is more sporadic at higher loads with this method. The distribution from this test is shown in Appendix 9.2,

5.2.3. Condition 1 Compared to Condition 3

The variable between Condition 1 and 3 is the rate at which the weight is applied. Where Condition 1 is loaded at the slow speed of 5 mm/min and Condition 3 is loaded at the fast rate of 20 mm/min. both tests were performed with guided compression and no stacking fixture. At the minimum load the deflections are almost identical however at the median and maximum load Condition 3 had lower deflections. The difference comes from the material not having as much time to expand. At the first loading the fixed plate is pushing in on the handle, collapsing the handle and the 2% of head space. Once the head space has collapsed the liquid is required to support the load, Water can be considered an incompressible fluid so the liquid is able to support the load. At the greater speeds the material yields less and thus the volume change isn't has great causing higher loads to occur at lower deflections. It was expected that the faster speed would be a more extreme test and would cause lower loads, and faster failure. This did not occur, as the package was given less time to expand and caused the deflections to decrease at the stacking loads.

Load	Condition 1	Condition 3	Difference
Minimum Load 1.54 kN	17.983 mm	18.033 mm	-0.050 mm
Median Load 2.68 kN	24.917 mm	23.733 mm	1.184 mm
Maximum Load 3.82 kN	37.450 mm	34.433 mm	3.017 mm

Table 10: Condition 1 and 3

Given the standard deviations of the deflections at each loading and the non-parametric distribution the Mann-Whitney U test have the results shown below. The Mann-Whitney U test gave the following percentages as the likelyhood of these tests yielding the same results

Mann Whitney U test	Condition 1 and Condition 3
Minimum Load 1.54 kN	76.24%
Median Load 2.68 kN	.58%
Maximum Load 3.82 kN	.02%

Table 11: Statistcal realtionship Condition 1 and 3

This shows that by changing the rate of loading with fixed plates and no stacking fixture there is no difference for the minimum of loading. However as the load the increases the chance of the test being related decreases to an insignificant amount, indicating the tests is non-similar and will not yield comparable results.

5.2.4. Condition 4, 5 mm/min, Guided Compression, Stacking fixture

Condition 4 was tested at the slow speed of 5 mm/min with guided compression and a stacking fixture as shown in Figure 2 to simulate the nesting of the jerricans.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	14.001 mm	23.250 mm	38.751 mm
Average	12.855 mm	22.746 mm	38.396 mm
Minimum	11.750 mm	21.584 mm	37.917 mm
Range	2.251 mm	1.667 mm	0.834 mm
Standard Deviation	0.570 mm	0.516 mm	0.328 mm

Table 12: Summary of Condition 4

Loads	All tests average	Condition 4	Difference
1.54 kN	14.43 mm	12.86 mm	1.57 mm
2.68 kN	23.37 mm	22.75 mm	0.62 mm
3.83 kN	37.26 mm	38.4 mm	-1.14 mm

Table 13: Condition 4 compared to all test.

As demonstrated in Table 13 the deflections were lower for the low loading with a slightly lower deflection at the medium loading and higher deflection at the high loading value. The rate of change is again different than the average; where lower deflections occur at the low loads and greater deflections at the high loads. Initially the stacking fixture increases the load bearing area. This will cause the loads to be reached faster resulting in lower deflections. Once the stacking fixture is pressed into the package the area is the same as it would be without the stacking fixture causing the load to drop slightly under the average.

5.2.5. Condition 1 Compared to Condition 4

The variable between Condition 1 and Condition 4 is the use of a stacking fixture. Both Conditions were tested at 5 mm/min and guided compression.

Load	Condition 1	Condition 4	Difference
Minimum Load 1.54 kN	17.983 mm	12.855 mm	5.129 mm
Median Load 2.68 kN	24.917 mm	22.746 mm	2.170 mm
Maximum Load 3.82 kN	37.450 mm	38.396 mm	-0.946 mm

Table 14: Comparison Condition 1 and Condition 4

At the low and medium stacking loads a much lower deflection is needed to cause the same load. This is due to the stacking fixture increasing the area in which the load is applied, for this package; the handle of the jerrican supports the majority of the initial loading, causing high deflection due to low structural integrity. The use of the stacking fixture places the load where the package is intended to support it. The stacking fixture better simulates actual products stacked on top of each other. At the high loadings, once the compression has reached a point under both Conditions where the compression plate is in full contact with the jerrican the deflections are becoming more similar. Despite the two tests becoming more similar the stacked fixture required more deflection at the high load opposite to having less deflection at the low and medium load.

Mann Whitney U test	**Condition 1 and Condition 4**
Minimum Load 1.54 kN	.02%
Median Load 2.68 kN	.02%
Maximum Load 3.82 kN	5.39%

Table 15: Statistcal realtionship 1 and 4

The U tests shows that there is no relationship at the low and medium loads and very little relationship at the higher loads. This shows that the addition of the stacking fixture once again changes the results and it is improbable that the tests will yield similar results.

5.2.6. Condition 6, 20 mm/min, Guided Compression, Stacking fixture

Condition 6 was run at the fast speed of 20 mm/min with guided compression and with the use of a stacking fixture. All of the samples were able to reach the maximum load and all samples were included in the evaluation.

	Minimum Load 1.54 kN	**Median Load 2.68 kN**	**Max Load 3.82 kN**
Max	10.667 mm	18.666 mm	34.667 mm
Average	9.468 mm	17.534 mm	32.868 mm
Minimum	8.333 mm	16.010 mm	31.001 mm
Range	2.334 mm	2.656 mm	3.667 mm
Standard Deviation	0.849 mm	0.832 mm	1.187 mm

Table 16: Condition 6 summary

Loads	All tests average	Condition 6	Difference
1.54 kN	14.43 mm	9.47 mm	4.96 mm
2.68 kN	23.37 mm	17.53 mm	5.84 mm
3.83 kN	37.26 mm	32.87 mm	4.39 mm

Table 17: Condition 6 compared to all tests

Condition 6 resulted in lower deflections at each loading interval. The least amount of deflection overall was observed in Condition. This shows that the load is reached much faster under these Conditions than any other method.

5.2.7. Condition 4 Compared to Condition 6

Both Conditions were performed with guided compression and a stacking fixture. The variable between these two tests was the rate at which the weights were loaded. Condition 4 was loaded at 5 mm/min and Condition 6 was loaded at 20 mm/min. This is similar to section 5.2.3 where Conditions 1 and 3 were compared; as the speed is the variable between the two different testing Conditions.

Load	Condition 4	Condition 6	Difference
Minimum Load 1.54 kN	12.855 mm	9.468 mm	3.387 mm
Median Load 2.68 kN	22.746 mm	17.534 mm	5.212 mm
Maximum Load 3.82 kN	38.396 mm	32.868 mm	5.529 mm

Table 18: Condition 4 compared to Condition 6

Unlike Table 10 that compares Condition 1 to Condition 3 where the difference is almost insignificant at low loads, the difference between Condition 4 and Condition 6 is significant at all loads. Conditions 1 and 3 were similar due to the handle being crushed at low loads. The use of the stacking fixture doesn’t compress the handle, eliminating the earlier similarity.

Mann Whitney U test	Condition 4 and Condition 6
Minimum Load 1.54 kN	.02%
Median Load 2.68 kN	.02%
Maximum Load 3.82 kN	.02%

Table 19: Statiscal realtionship 4 and 6

The U test shows no relationship between these two tests. Table 19 shows the U test results from Condition 1 and 3. Contrary to the high relationship that occurred at the low loading, no relationship was found when the speed is varied and a stacking fixture is used for guided compression. It was expected that this comparison would be the same as the comparison between Condition 1 and 3. The comparison of Conditions 4 and 6 showed no relation at any loads.

5.2.8. Condition 7, 5 mm/min, Unguided Compression, no Stacking Fixture

Condition 7 was performed at the slow speed of 5 mm/min on a swivel platen without the usage of a stacking fixture. This test did not run as easily as the guided compression, as some of the samples did not reach the 150 mm extension, requiring them to be disregarded from the results. Additional samples were tested; Condition 7 had a total of nine samples that were able to be used for comparison.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	21.167 mm	28.084 mm	41.584 mm
Average	19.398 mm	26.287 mm	39.972 mm
Minimum	18.167 mm	25.417 mm	38.250 mm
Range	3.000 mm	2.667 mm	3.334 mm
Standard Deviation	1.045 mm	0.956 mm	1.047 mm

Table 20: Condition 7 summary

Loads	All tests average	Condition 7	Difference
1.54 kN	14.43 mm	19.4 mm	-4.97 mm
2.68 kN	23.37 mm	26.29 mm	-2.92 mm
3.83 kN	37.26 mm	39.97 mm	-2.71 mm

Table 21: Condition 7 compared to all tests

The average deflection of the Condition 7 results were greater than the average, meaning the lesser load is required to cause failures, and that Condition 7 is more extreme than the average test. It is expected the swivel plate will find the weakest part of a package so it is expected that the deflections would be higher. Histograms of Condition 7 can be found in Section 9.2

5.2.9. Condition 1 Compared to Condition 7

Condition 1 and Condition 7 were both performed at the slow speed of 5 mm/min and with no stacking fixture. The variable was the type of compression being performed, as either guided or unguided by use of a swivel platen.

Load	Condition 1	Condition 7	Difference
Minimum Load 1.54 kN	17.983 mm	19.398 mm	-1.415 mm
Median Load 2.68 kN	24.917 mm	26.287 mm	-1.370 mm
Maximum Load 3.82 kN	37.450 mm	39.972 mm	-2.522 mm

Table 22: Condition 1 compared to Condition 7

As shown by Table 22 the swivel platen needed more deflection to reach the same loads, suggesting that the swivel platen found the weakest part of the package

Mann Whitney U test	Condition 1 and Condition 7
Minimum Load 1.54 kN	6.62%
Median Load 2.68 kN	4.12%
Maximum Load 3.82 kN	.09%

Table 23: Statiscal realtionship 1 and 7

The U test also showed that there is little relationship between the two common tests with the variable being the type of compression. At the lower stacking loads the swivel platen doesn't rotate significantly. If no rotation occurs, the test Conditions would be the same. It was expected that the average deflection from the swivel plate would be greater than the deflection from the guided compression plate, which was confirmed.

5.2.10. Condition 9, 20 mm/min, Unguided Compression, Stacking Fixture

Condition 9 was run at the fast speed of 20 mm/min and unguided compression without the use a stacking fixture. A total of 10 samples were run with samples 4 and 9 being rejected due to the specimen slipping out before the compression was able to reach 150 mm. The remaining samples were analyzed and results are shown in the below Table.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	16.334 mm	22.669 mm	37.334 mm
Average	16.125 mm	22.417 mm	36.375 mm
Minimum	15.667 mm	22.000 mm	35.000 mm
Range	0.667 mm	0.669 mm	2.334 mm
Standard Deviation	0.248 mm	0.296 mm	0.677 mm

Table 24: Condition 9 summary

Loads	All Tests average	Condition 9	Difference
1.54 kN	14.43 mm	16.13 mm	-1.70 mm
2.68 kN	23.37 mm	22.24 mm	1.13 mm
3.83 kN	37.26 mm	36.38 mm	0.88 mm

Table 25: Condition 9 compared to all tests

Condition 9 required more defection at the initial low loading than the All Test average.

5.2.11. Condition 7 Compared to Condition 9

The comparison of these two Conditions will be similar to the comparison of Condition 1 and 3 made in Section 5.2.3, as the variable between these two tests is the compression rate at which the test was performed. In this case both tests were done using an unguided platen and no stacking fixture.

Load	Condition 7	Condition 9	Difference
Minimum Load 1.54 kN	19.398 mm	16.125 mm	3.273 mm
Median Load 2.68 kN	26.287 mm	22.417 mm	3.870 mm
Maximum Load 3.82 kN	39.972 mm	36.375 mm	3.597 mm

Table 26: Condition 7 compared to Condition 9

The faster speed once again required less deflection for the desired load to be reached and in every case a higher deflection was needed with the slower speed.

Mann Whitney U test	Condition 7 and Condition 9
Minimum Load 1.54 kN	.06%
Median Load 2.68 kN	.06%
Maximum Load 3.82 kN	.06%

Table 27: Statitscal realtionship 7 and 9

The U test showed that these two tests are not comparable, at any of the stacking loads. Table 10 indicates the U test of Conditions 1 and 3 will most likely yield similar results at low loads. However by varying the speed with a swivel platen there is no relationship even at the low loads. This was unexpected since the rotation of the plate doesn't depend on the speed and at low loads there is little rotation. From those observations it was expected that the low load would have a high relationship.

5.2.12. Condition 10, 5 mm/min Unguided Compression, Stacking Fixture

Condition 10 was performed at the slow compression rate of 5 mm/min with the use of the stacking fixture and unguided compression. While testing under these Conditions it was observed that many of the samples slipped out from under plate and often times removing the stacking fixture from the swivel platen. Ten samples were tested, Specimens 1,2,3,6,7,8,9,10 were all discarded as outliers or the samples slipped out from under the platen before the minimum deflection of 150 mm was reached. Additional samples were tested as part of the testing in Section 5.4. The corrected results are shown in Table 28

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	13.417 mm	33.334 mm	43.417 mm
Average	11.680 mm	32.375 mm	41.180 mm
Minimum	11.167 mm	31.167 mm	39.916 mm
Range	2.250 mm	2.167 mm	3.501 mm
Standard Deviation	0.864 mm	0.864 mm	1.332 mm

Table 28: Summary of Condition 10

It is observed that the median loading is where the results were the most inconstant and the sample set had more repeatable values at the low and high loads. This was due to the fact that the floating plate would tend to settle around this loading.

Loads	All tests average	Condition 10	Difference
1.54 kN	14.43 mm	11.68 mm	2.75 mm
2.68 kN	23.37 mm	32.37 mm	-9.01 mm
3.83 kN	37.26 mm	41.18 mm	-3.93 mm

Table 29: Condition 10 compared to all tests

Condition 10 had similar results to the average deflection at the low loads but had greater defections at the medium and low loads. The maximum deflections came from Condition 10, sample 8.

5.2.13. Condition 4 Compared to Condition 10

The difference between these was the type of compression used, similar to the comparison of Condition 1 and Condition 7. Both Condition 4 and Condition 10 were performed at the slow compression rate with the use of the stacking fixture. The variable is the type of compression that was used.

Load	Condition 4	Condition 10	Difference
Minimum Load 1.54 kN	12.855 mm	11.680 mm	1.174 mm
Median Load 2.68 kN	22.746 mm	32.375 mm	-9.628 mm

Maximum Load 3.82 kN	38.396 mm	41.180 mm	-2.784 mm

Table 30: Comparison of 4 and 10

The use of the floating platen again required more defection to reach the same predetermined load, similarly to how more deflection was required from Condition 7 when compared to Condition 1.

The U test shows the following results.

Mann Whitney U test	Condition 4 and Condition 10
Minimum Load 1.54 kN	2.62%
Median Load 2.68 kN	.14%
Maximum Load 3.82 kN	.14%

Table 31: Statistcal realtionship between 4 and 10

Much like the comparison at the low loads of Condition 1 and Condition 7 we see a slight relationship at the low stacking load.

5.2.14. Condition 7 Compared to Condition 10

The variable between Condition 7 and Condition 10 was the use of the stacking fixture; this comparison is the same variable as the comparison between Condition 1 and. Condition 4. However, in the cases of Condition 7 and Condition 10 the compression type is unguided and the rate of loading is 5 mm/min.

Load	**Condition 7**	**Condition 10**	**Difference**
Minimum Load 1.54 kN	19.398 mm	11.680 mm	7.718 mm
Median Load 2.68 kN	26.287 mm	32.375 mm	-6.088 mm
Maximum Load 3.82 kN	39.972 mm	41.180 mm	-1.208 mm

Table 32: Comparison between 7 and 10

Mann Whitney U test	**Condition 7 and Condition 10**
Minimum Load 1.54 kN	0.18%
Median Load 2.68 kN	0.18%
Maximum Load 3.82 kN	6.77%

Table 33: Statistical realtionship 7 and 10

The higher relationship that is found at the median loadings was found because of the higher than average standard deviation that occurred in test Condition 10 at the median loading. The other stacking loads show no relationship

The maximum overall deflections were recorded from either sample 7 or sample 10 showing that packagings cannot support the same load when being tested by a swivel platen.

5.2.15. Condition 12, 20 mm/min, Unguided Compression, Stacking Fixture

The last test that was run to determine the variation in the different methods was performed at the fast speed of 20mm/min with unguided compression and the use of the stacking fixture. All of the standard deviations from each loading were found to be less than a millimeter. Samples 2, 3 and 7 were discarded as a result of not reaching 150mm before the overall results from the remaining test are shown below.

	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	11.667 mm	18.333 mm	38.333 mm
Average	9.933 mm	16.933 mm	37.366 mm
Minimum	9.000 mm	16.000 mm	36.000 mm
Range	2.667 mm	2.334 mm	2.334 mm
Standard Deviation	0.843 mm	0.699 mm	0.711 mm

Table 34: Summary of Conditional 12

Loads	All tests average	Condition 12	Difference
1.54 kN	14.43 mm	9.93 mm	4.50 mm
2.68 kN	23.37 mm	16.93 mm	6.44 mm
3.83 kN	37.26 mm	37.37 mm	-0.11 mm

Table 35: Condition 12 compared to all tests

Test 12 reached the stacking loads at much lower deflections than the average tests, for the minimum and median loads. Once the high stacking load was reached, the value was closer to the average.

5.2.16. Condition 9 Compared to Condition 12

Conditions 9 and 12 were both tested at the high compression rate of 20 mm/min and with unguided compression; the variable between the two tests was the use of a stacking fixture similarly to the comparison of 7 and 10.

Load	Condition 9	Condition 12	Difference
Minimum Load 1.54 kN	16.125 mm	9.933 mm	6.192 mm
Median Load 2.68 kN	22.417 mm	16.933 mm	5.484 mm
Maximum Load 3.82 kN	36.375 mm	37.366 mm	-0.991 mm

Table 36: Comparison 9 and 12

. Due to a large standard deviation, a relationship may be statistically proven without theoretical basis. The comparison between Condition 9 and Condition 12 do not show the same relationship that was found in the comparison of Condition 7 and 10 given the same variable. This supports the idea that the high relationship was caused by the high standard deviation.

5.2.17. Condition 10 Compared to Condition 12

This comparison shows the difference the compression rate will make with unguided compression and a stacking fixture.

Load	Condition 10	Condition 12	Difference
Minimum Load 1.54 kN	11.680 mm	9.933 mm	1.747 mm
Median Load 2.68 kN	32.375 mm	16.933 mm	15.442 mm
Maximum Load 3.82 kN	41.180 mm	37.366 mm	3.814 mm

Table 37: Comparison of 10 and 12

As shown in Table 37 the average deflection was again less because of the reduced amount of time the material has to expand. All values are lower than that of test average the large difference in the median loads can be explained by the high range of values that were observed during Condition 10 at the median load. The other values are still much lower on average. Interpolating estimation for median loading of the samples based upon minimum and maximum loading indicates that the test results would still yield deflections lower than those observed during Condition 10.

The U test shows that there is no relation between these tests just like there was none for the compression between Conditions 4 and 6.

Mann Whitney U test	Condition 10 and Condition 12
Minimum Load 1.54 kN	0.79%
Median Load 2.68 kN	0.14%
Maximum Load 3.82 kN	0.14%

Table 38: Statistcal realtionship 10 and 12

Even with the high variation of the median load of Condition 10 there is no relationship between two different testing Conditions.

5.2.18. Summary of all Testing Conditions

All summarized data was put into a table and the average value of the key components was then analyzed as shown in the Table 39.

Average of all tested values			
Load	1.54 kN	2.68 kN	3.82 kN
Average of the maximum deflection	15.65 mm	24.31 mm	38.57 mm
Average deflection	14.43 mm	23.37 mm	37.26 mm
Average of the minimum deflection	13.57 mm	22.39 mm	35.80 mm
Average range deflection	2.07 mm	1.93 mm	2.77 mm

Table 39: Average deflection at stacking loads giving any Condition

These values are used as a base line to establish what we can expect from one test to another. If all tests were the same it would be expected that the average from any test would be comparable to the average of all the tests.

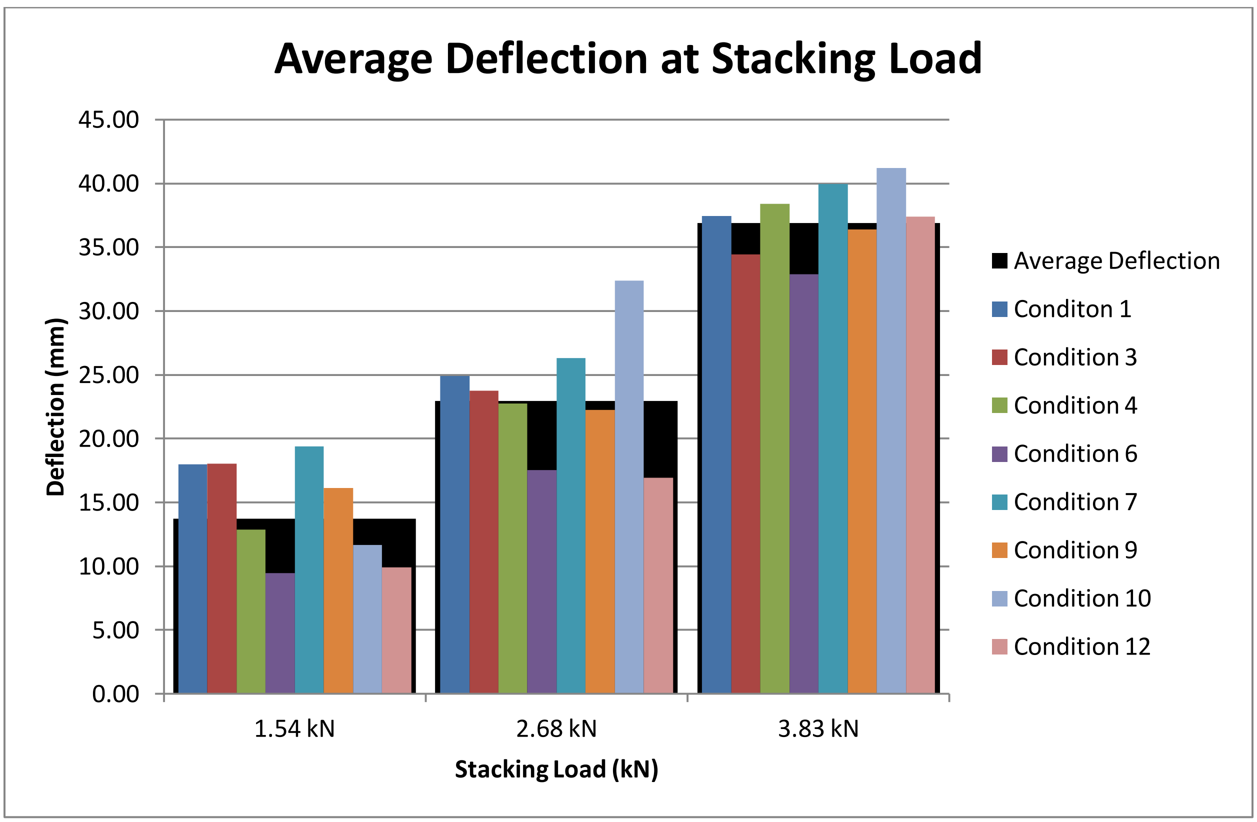

Figure 11: Average deflection compared to average overall deflection

5.3. Stacking Test

Four specimens were used in a creep study to determine the rate of creep with guided and unguided compression. The minimum and maximum stacking load of 1.54 kN and 3.82 kN were applied using both the unguided and guided compression. Each corner or the plate was measured for deflection and the average deflection is plotted in Figure 12

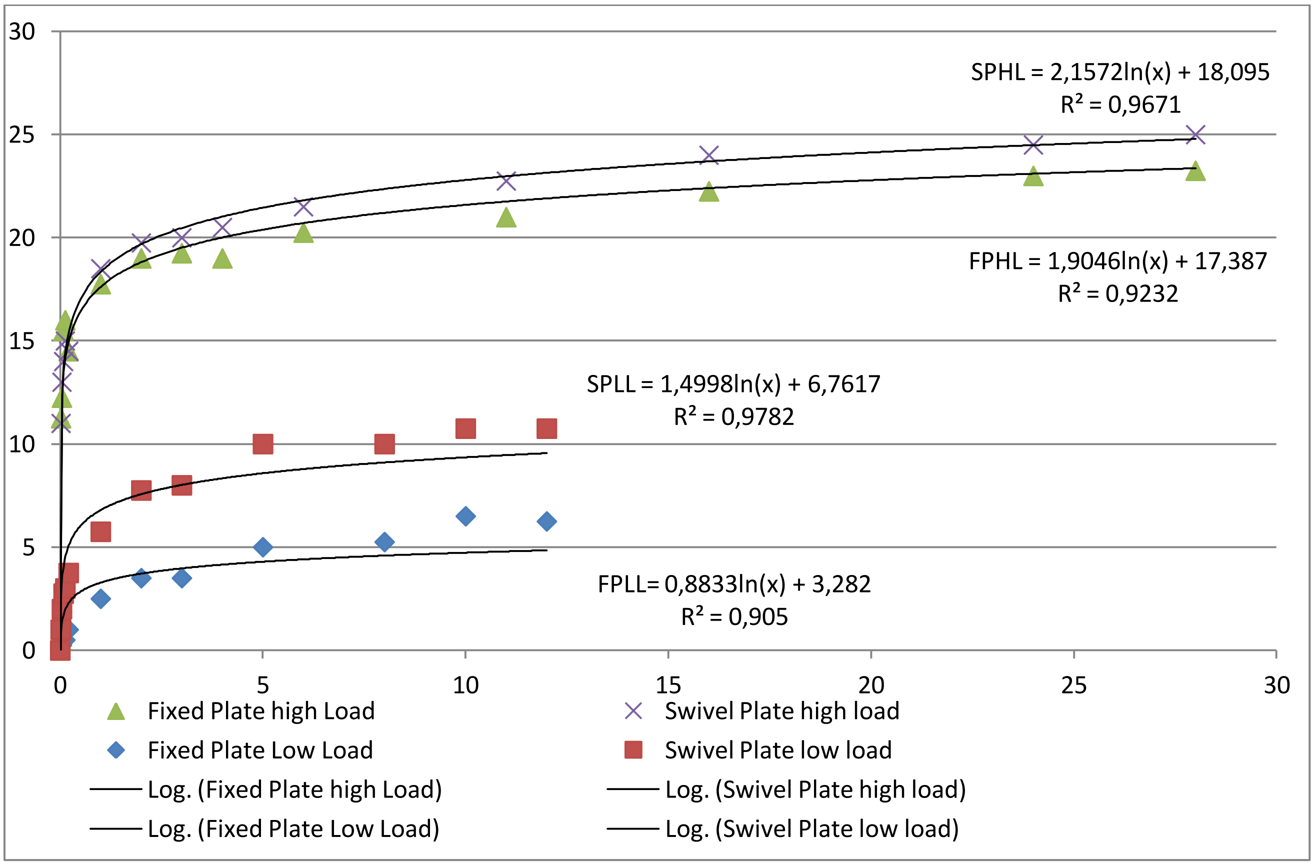

Figure 12: Static Stacking Creep Rates

As shown by Figure 12, for both the low and high loading the swivel platen had a higher rate of creep which is supported by "Compressive strength and creep of recycled HDPE", and the findings in section 5 where the swivel platen will have a higher initial strain once the load is placed. After the initial strain, the higher strain rate will then creep faster. From the fitted line, the deflections at the 28 day period are shown in the Table 40.

Total creep after 28 days			
Load	Fixed Platen	Swivel Platen	Difference
1.58 kN	15.69 mm	21.69 mm	-6.00 mm
3.84 kN	56.59 mm	62.66 mm	-6.07 mm

Table 40: Creep difference

Since these measurements were taken after the load has been applied it is important to add in the deflection found from compression testing. The rate at which the load was applied was estimated to be 17mm/min, the average deflection from the similar Conditions with the 20 mm/min rate were used for comparison. The average deflections at the two loads for each case were added to the function found in the creep study. This is necessary since the deflection was not measured until a load was applied. In both cases it was found that an additional 6 mm deflection would occur after a 28 day period.

5.4. Horizontal force results measuring the angle

Seven samples were tested at the center position as located by use of the CADD drawing described in section 3.2.6, four samples were tested at the Compression rate of 5 mm/min and three were tested at the high compression rate of 20 mm/min. It was determined that the rate did not contribute to angle of the swivel platen, indicating that the angle was completely dependent on the average deflection of the jerrican. A third order polynomial was used to fit the average angles for the first 60 mm, as shown in the Figure 13 below.

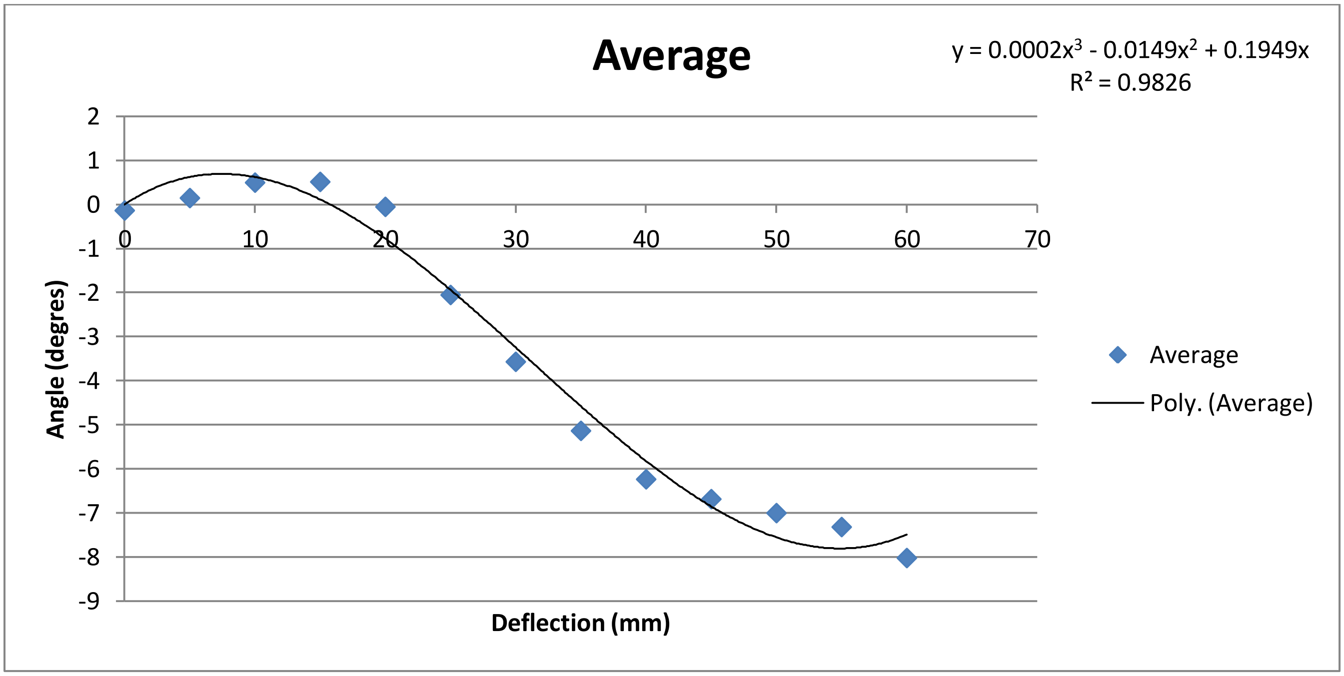

Figure 13: Average angle versus deflection

This equation was used along with the recorded load at a deflection to determine the resultant vector. The values for each swivel platen are shown in Table 41 below

	Resultant load	Instron load	Difference
Condition 7	1.538	1.538	0
Condition 9	1.538		0
Condition 10	1.538		0
Condition 12	1.538		0
Condition 7	2.681	2.68	0.001
Condition 9	2.681		0.001
Condition 10	2.683		0.003
Condition 12	2.68		0
Condition 7	3.829	3.823	0.006
Condition 9	3.828		0.005
Condition 10	3.829		0.006
Condition 12	3.828		0.005

Table 41: Resultant force calculation

As shown, the maximum difference in the resultant load compared to the load as calculated by the load cell from the Instron is 6 N (1.3 pounds). This load was not significant enough to cause a revaluation of the deflections as found from the load cells. In addition the horizontal loading component will only contribute to vertical deflection if the package were to buckle.

The jerricans that were tested in the experiment were filled with water and are rigid so that no buckling would occur. These results show that the resultant load is close enough to the load as calculated by the Instron.

5.4.1. Pressure Mat Results

The pressure mat was unable to capture accurate load values to compare to the compression data. Qualitatively the test showed a stacking fixture doesn’t affect how the bottom of the jerrican responds to the compression. The rate at which the load is applied will not make a noticeable difference on the pressure mat. From the Instron results it is understood that the loads will be reached at lower deflections due to the material not having enough time to expand. This would be in relation to the recorded area that could not be accurately determined by the pressure mat.

The final variable of the type of compression used was able to be captured from the use of the pressure mat. As shown in Figures 14 and 15 below

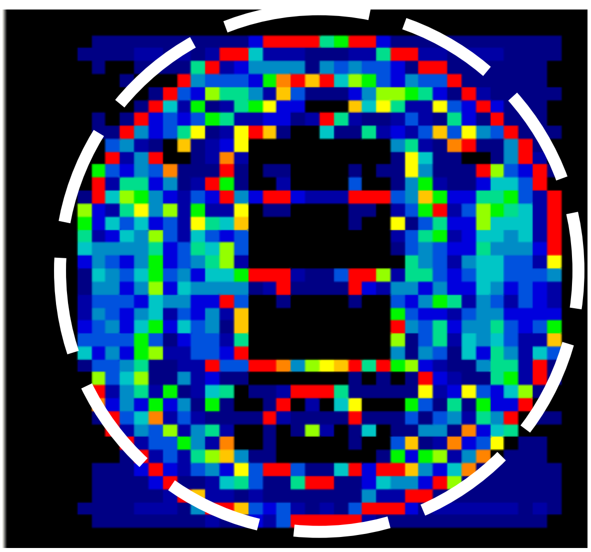

Figure 14: Fixed compression force distrubtion

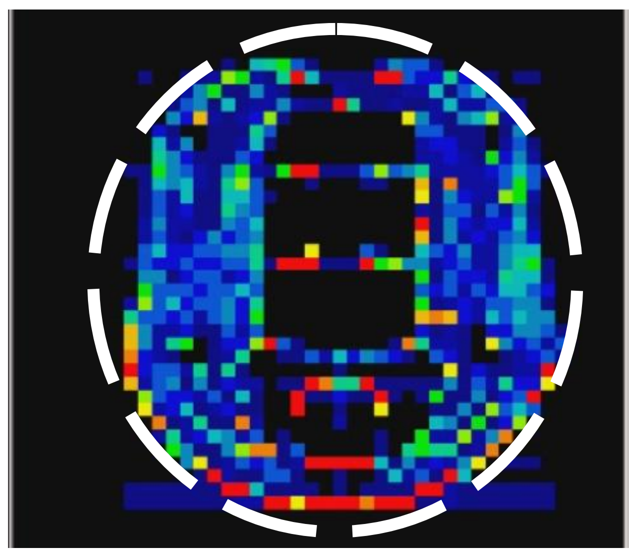

Figure 15: Unguided compression force distrubtion

As shown in Figure 14 the fixed platen is showing a uniform and almost perfectly circular force distribution, where the swivel platen would have localized stress concentrations, as shown in Figure 15.

As Shown in Figure 15, the front structure of the jerrican, near the area which the cap is located, is structurally stronger than the opposite sides of the jerrican. The resulting free body diagrams show how the force is distributed through the package and how the package is affected by the lateral shift. The force will always be applied perpendicular from the compression plate. The package will be held in place by friction where it comes in contact with both compression plates, these results in package itself becoming skewed as shown by the dashed lines in Figure 16 on the right.

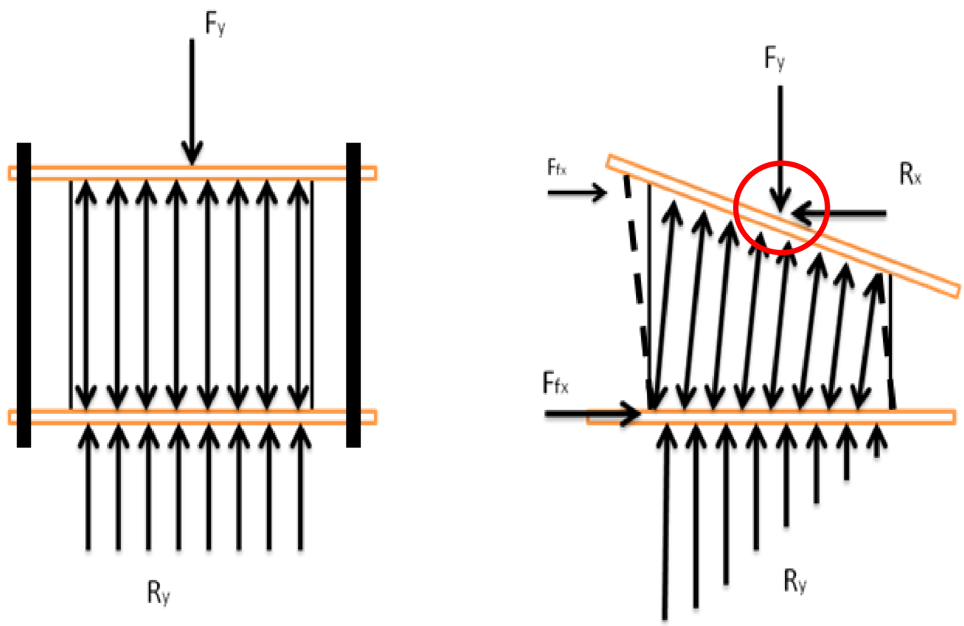

Figure 16: Free body diagrams guided and unguided compression

Too much rotation will cause the package to slip out from under the compression plate. The jerricans used for testing would often cause the plate to rotate backward, resulting in the force to be unevenly distributed and shifted towards the front of the package. The swivel platen was attached the same compression tester used in the fixed platen testing conditions. The deflection values were gathered from equipment outputs. The average deflections were obtained using the swivel plate. As one side tilts downward the other edge will rise. The resulting deflection will then be negative depending on the location of the jerrican that the measurement was taken from.

5.5. Pressure test

A pressure test is one of the other design type tests in the UN recommendations for the transport of dangerous goods. For this test a valve was inserted in to the side of the package, shown by Figure 17. Test Conditions 4, 6 and 12 were repeated with the attached valve. These tests were chosen because of the added positional control that the stacking fixture contributes to the swivel platen. To compare these results to the fixed platen and the slower compression rate, Test Conditions 4 and 6 were chosen. These tests showed an increase in pressure at the faster speeds along with an increase in the vertical component of the load. Since Condition 6 and 12 showed similar pressure profiles with a decreased load with Sample 12, it can be concluded that the resultant forces are also similar, since the area of the valve remains unchanged.

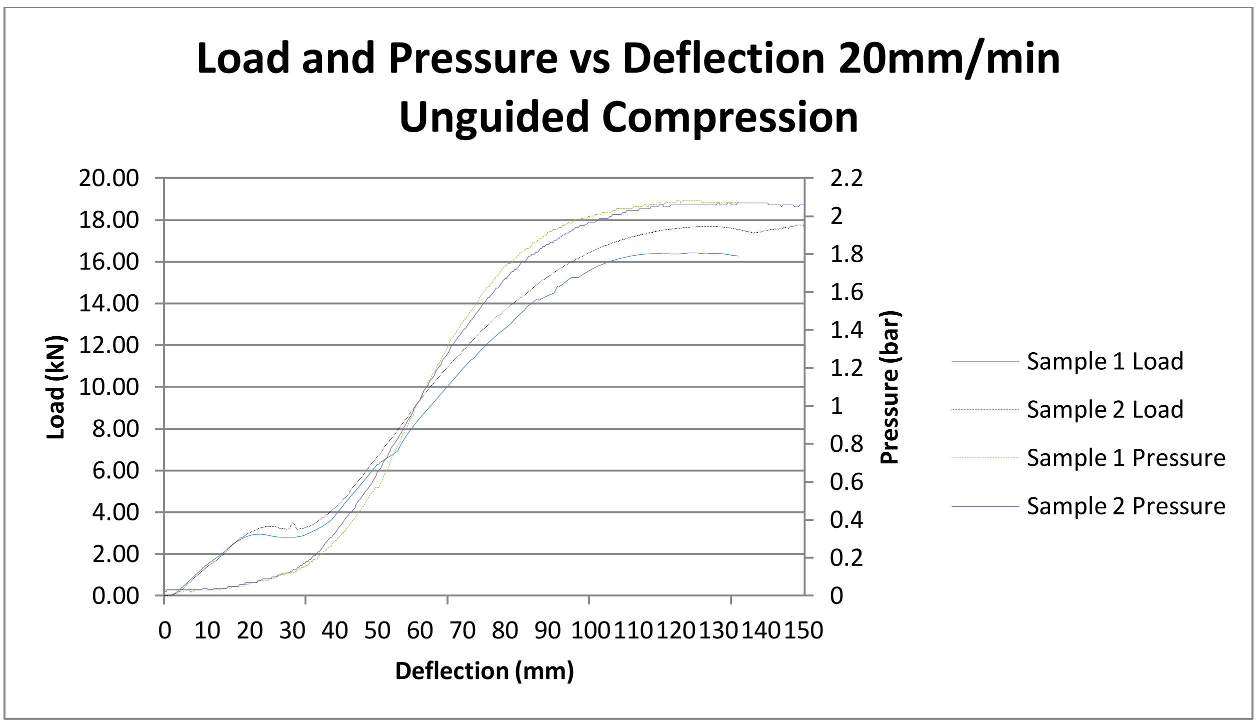

Figure 17

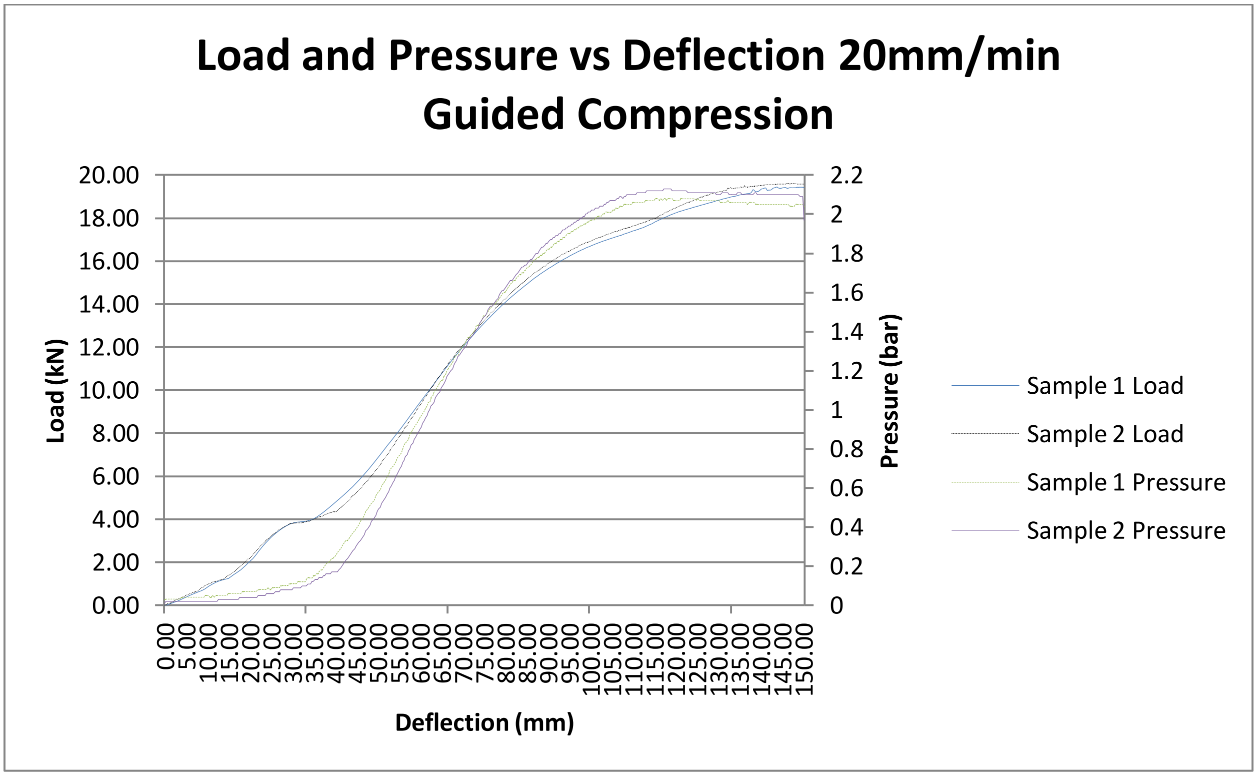

Figure 18

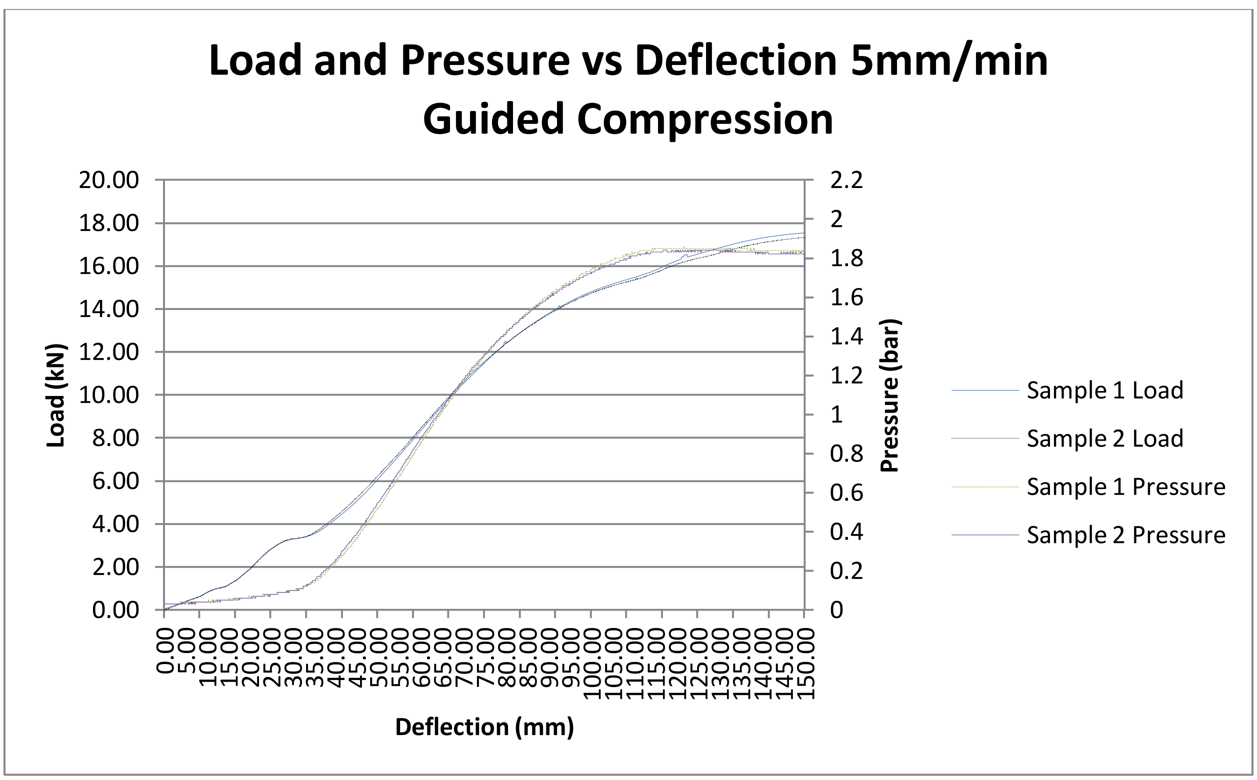

Figure 19

Comparing Figures 17 and 18 there is a decreased load despite the pressures remaining the same. This further shows that the loss in force is due to the fact that the load cells are only able to capture the vertical force as shown in the Figure 16.

5.6. Digital imaging correlation (DIC)

To better understand how the local deflection is affected by the use of a swivel platen a DIC test was performed with both the fixed and swivel platen. The DIC recorded the local deflection at the area under the cap since it determined that the cap is the part of the jerrican that causes the swivel platen to tilt backwards. This was difficult because the top of the jerrican starts to fold and the points used for locating the deflection move out of view of the camera.

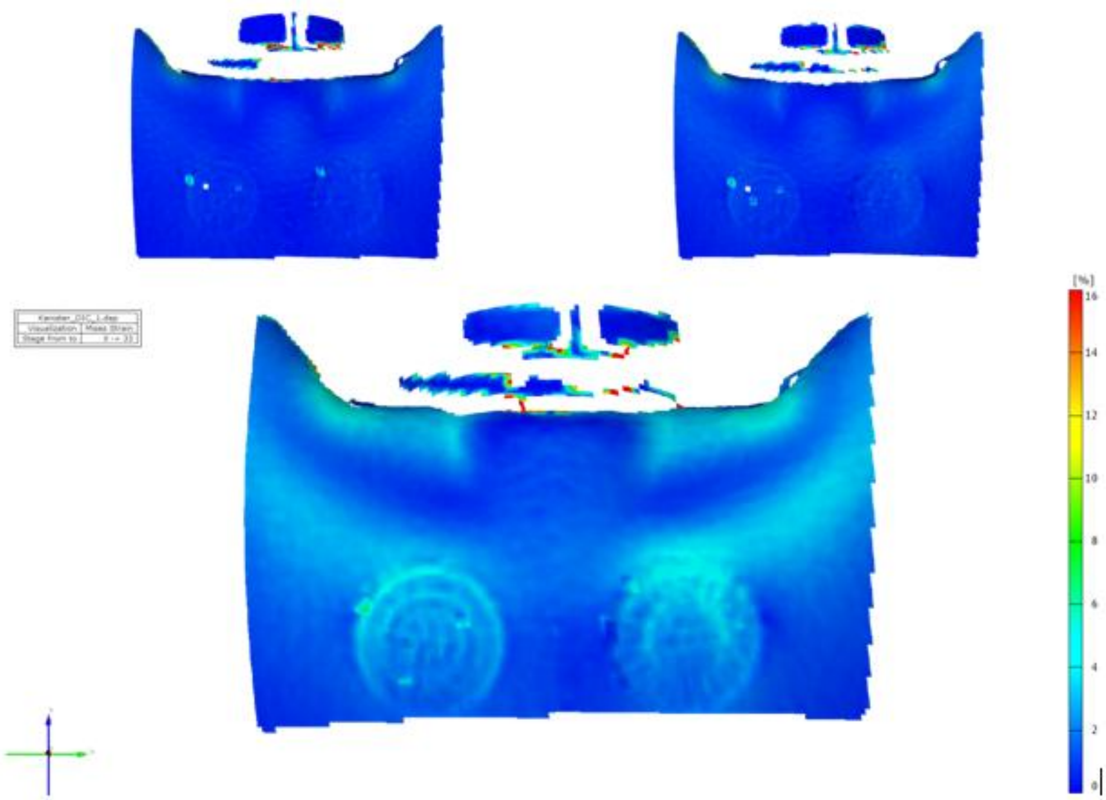

Figure 20: Front of jerrican at each stacking load

Figure 20 shows three images that were taken when the jerrican reached each of the stacking loads. The lowest load is shown in the upper left and the highest load is shown on the bottom.

During the loading stress concentrations form around the imprints and away from extra material that has been added to support the cap.

The two images in Figure 21 show the side of the jerrican during compression. The upper left corner of each image shows an increase in the localized strain.

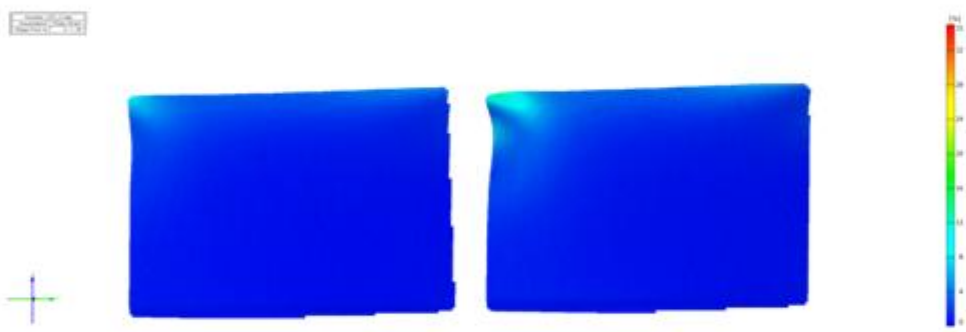

Figure 21: Side of jerrican, guided (left), unguided (right)

The image to the right shows the swivel platen sample, indicating an increase in localized strain on the back of the jerrican. This is caused by the swivel platen being pushed upward and compressing the back of the jerrican more. These localized stresses are critical for evaluating failure in the package especially when handling dangerous liquids. Dangerous liquids can cause material deterioration which will increase the effects of stress cracking causing a failure that may not occur from one test to the other.

5.7. Positional Study

A CAD model shown in Figure 9 was printed to scale and used to locate the jerrican in the positions as shown. The load and deflection were plotted and compared at each position. As shown in Figure 23. Position 5 is where the center of the jerrican was aligned with the center of the swivel platen; the center of the jerrican was moved to every location and appropriately aligned. A stacking fixture was created by using a bottom section of a jerrican and filled with epoxy to create a rigid fixture. This fixture also was used to control the alignment with the model in Figure 22. Compression was performed at a rate of 20 mm/min until the package reached 150 mm of deflection or until the swivel plate reached 20° or rotation which would cause contact with the top of the compression tester. The angle of the plate was recorded at 10 mm increments along the X axis and Z axis as shown in Figures 23 and 24. These values were used to calculate the resultant load that was placed on the package. This load was found to be an insignificant difference from what was recorded from the load cells. The meassured angles were also used to plot the rotation at a certain deflection and are shown in the Figure 13.

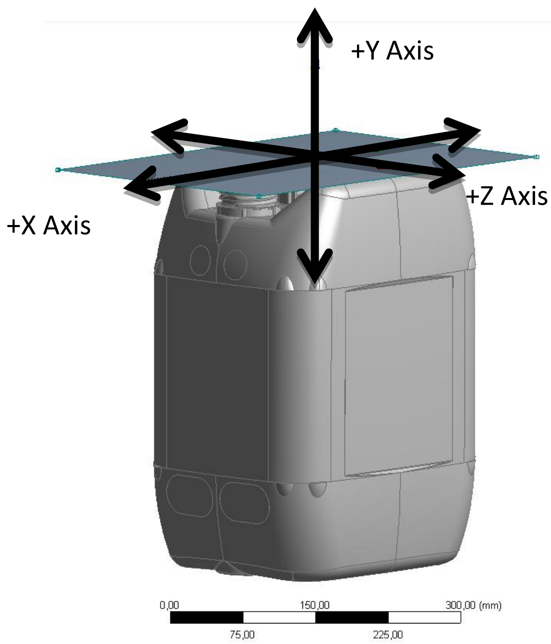

Figure 22: 3d model with coordinate system

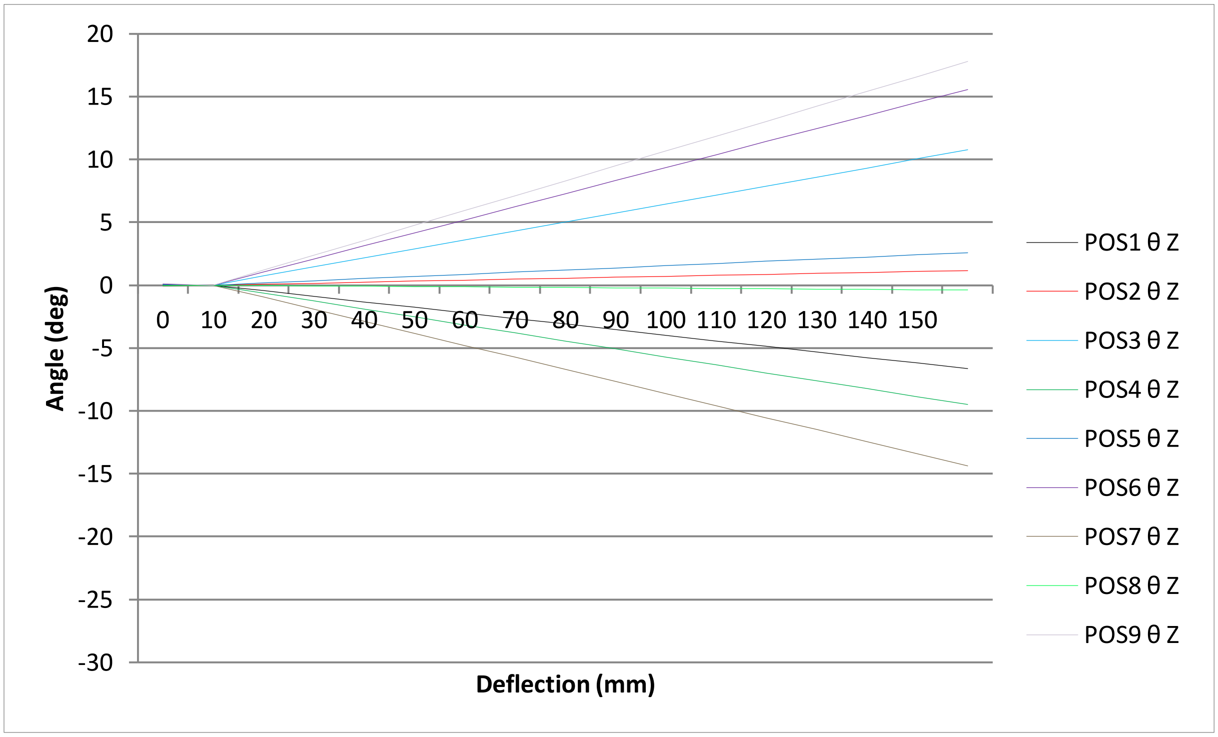

Figure 23: Angle vs Deflection θz

Theta Z (θz) as shown by Figure 23 had similar angles due to the symmetry about the XY plane. When the XY plane was centered (Positions 2, 5, and 8) there was little movement about the X axis further showing the symmetry about the XY plane. Figure 24 shows the rotation about the Z axis. When centered the cap causes the plate to tilt backwards decreasing the angle between the Y and X axis Theta X (θx).

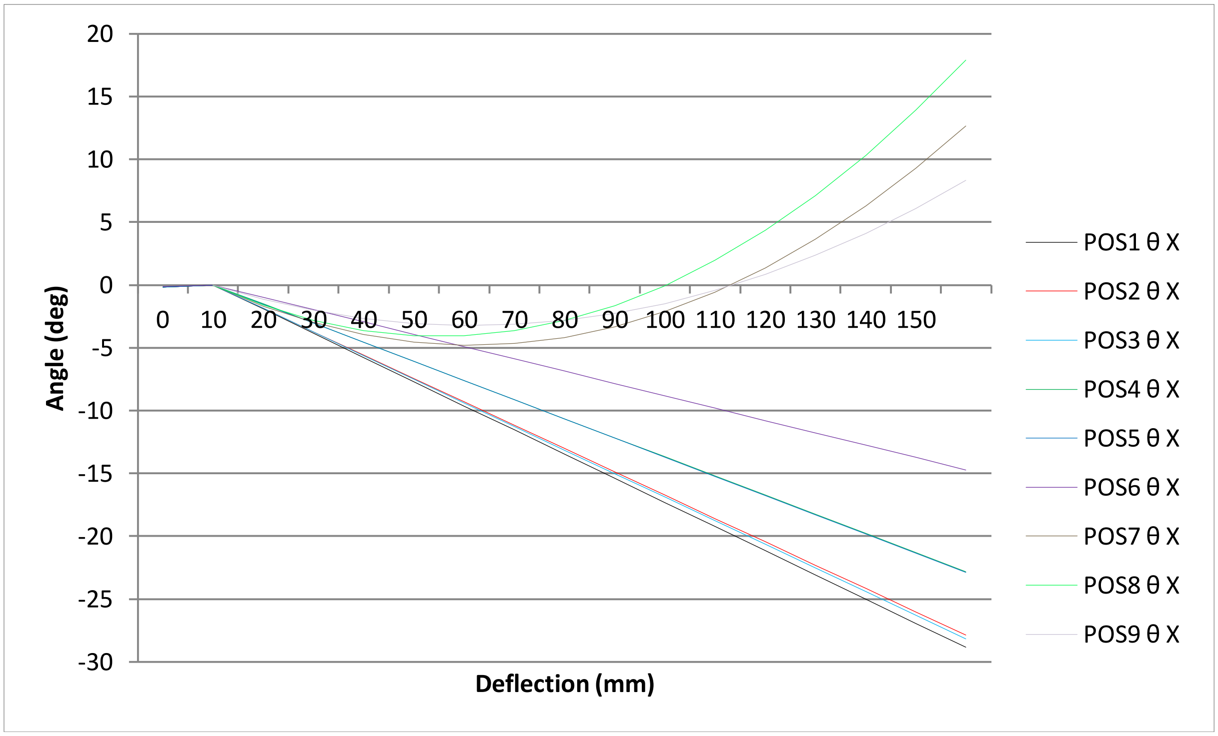

Figure 24: Angle vs. Deflection θx

Due to the cap of the jerrican and a design feature to strengthen the area under the cap it is harder to compress than the back side of the jerrican. The jerrican favored a negative tilt about the Z axis decreasing the angle between the Y, X axis. However, shifting the center 1 cm in the negative X direction caused the plate to tilt in the opposite direction increasing the angle θx at higher deflections. A second order polynomial was used to fit the trend of the data, unlike the other positions which all trended to a linear relationship to the deflection. Variance in jerrican placement may have influenced the results of the test at Position 6, which caused a less severe trend line slope for the position

The stacking loads were then selected and the average deflection of the swivel platen as found by the compression machine was recorded. These values are shown in Table 42.

Positional Study Deflections at Stacking Loads			
	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
1	7.67 mm	30.00 mm	38.00 mm
2	9.00 mm	30.33 mm	38.33 mm
3	8.67 mm	30.33 mm	37.67 mm
4	9.00 mm	17.00 mm	36.00 mm
5	9.67 mm	16.00 mm	37.00 mm
6	10.00 mm	17.00 mm	36.67 mm
7	9.33 mm	19.00 mm	34.67 mm
8	9.33 mm	15.67 mm	32.67 mm
9	10.67 mm	19.33 mm	33.33 mm
30°/5	7.67 mm	17.33 mm	40.00 mm
60°/5	9.00 mm	17.33 mm	39.33 mm
	Minimum Load 1.54 kN	Median Load 2.68 kN	Max Load 3.82 kN
Max	10.67 mm	30.33 mm	40.00 mm
Average	9.09 mm	20.85 mm	36.70 mm
Minimum	7.67 mm	15.67 mm	32.67 mm
Range	3.00 mm	14.67 mm	7.33 mm
Standard Deviation	0.90 mm	6.12 mm	2.35 mm

Table 42: Deflection at positions

The greatest difference is found from the median load of 2.68 kN at Positions 1, 2, and 3 where the center is moved in the positive X direction 1 cm. This resulted in a 13 mm increase from average deflection. Each sample deflection at the minimum stacking load was within a 3 mm spread and the deflections from the maximum stacking load all fell within a 7.33 mm spread. At the high stacking load it is important to consider that the angle would have completely shifted from a negative angle to a positive for Positions 7, 8, and 9. This would result in the swivel platen be tilting downward instead of upward, pressing in the cap. The greatest change is in the local deflection and not in the average deflection. The average deflection from an additional 10 samples at center was used to quantify the difference in deflection based on the position, and shown in Table 43.

Load	Position	Deflection (mm)	Average Deflection at Center (mm)	Difference (mm)
Minimum Load 1.54 kN	1	7.67	9.93	-2.27
	2	9.00		-0.93
	3	8.67		-1.27
	4	9.00		-0.93
	5	9.67		-0.27
	6	10.00		0.07
	7	9.33		-0.60
	8	9.33		-0.60
	9	10.67		0.73
	30	7.67		-2.27
	60	9.00		-0.93
Median Load 2.68 kN	1	30.00	16.93	13.07
	2	30.33		13.40
	3	30.33		13.40
	4	17.00		0.07
	5	16.00		-0.93
	6	17.00		0.07
	7	19.00		2.07
	8	15.67		-1.27
	9	19.33		2.40
	30	17.33		0.40
	60	17.33		0.40
Max Load 3.82 kN	1	38.00	37.37	0.63
	2	38.33		0.97
	3	37.67		0.30
	4	36.00		-1.37
	5	37.00		-0.37
	6	36.67		-0.70
	7	34.67		-2.70
	8	32.67		-4.70
	9	33.33		-4.03
	30	40.00		2.63
	60	39.33		1.97

Table 43: Positions vs deflection at center

7. ERROR ANALYSIS

7.1. Statistical

Two separate statistical methods were used to evaluate the results and infer similarity between test methods with a 95% confidence interval. The two methods that were used were the Students T Test which should only be used for normal distributed data. An insufficient number of samples were tested to be able to confirm if the data would be normally distributed or not. The second method is the Mann-Whitney U test which compares the median instead of the means as in the T test. This allows for statistical testing of data without a normal distribution. The U test yielded the following overall results

T Probability			
Samples	Minimum Load 1.54 kN	Mean Load 2.68 kN	Max Load 3.83 kN
1,3	88.25%	0.32%	0.00%
1,7	0.81%	0.61%	0.01%
1,4	0.00%	0.00%	1.72%
4,6	0.00%	0.00%	0.00%
4,10	1.89%	0.00%	0.33%
7,9	0.00%	0.00%	0.00%
7,10	0.00%	0.00%	9.42%
10,12	0.25%	0.00%	0.04%

U Probability			
Samples	Minimum Load 1.54 kN	Mean Load 2.68 kN	Max Load 3.83 kN
1,3	76.24%	0.58%	0.02%
1,7	6.62%	4.12%	0.09%
1,4	0.02%	0.02%	5.39%
4,6	0.02%	0.02%	0.02%
4,10	2.62 %	0.14%	0.14%
7,9	0.06%	0.06%	0.06%
7,10	0.18%	0.18%	6.77%
10,12	0.79%	0.14%	0.14%
9,12	0.04%	0.04%	2.09%

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9. APPENDICES

9.1. Mini Tab Calculation

9.1.1. Session log

03.08.2012 08:12:03

```
Welcome to Minitab, press F1 for help.
Executing from file: C:\Program Files (x86)\Minitab 15\English\Macros\Startup.mac

 This Software was purchased for academic use only.
 Commercial use of the Software is prohibited.
```

Histogram of Stacking LoadsTest1 1,54

Histogram of Stacking LoadsTest1 2,68

Histogram of Stacking LoadsTest1 3,82

Histogram of Stacking LoadsTest3 1,54

Histogram of Stacking LoadsTest3 2,68

Histogram of Stacking LoadsTest3 3,82

Histogram of Stacking LoadsTest4 1,54

Histogram of Stacking LoadsTest4 2,68

Histogram of Stacking LoadsTest4 3,82

Histogram of Stacking LoadsTest6 1,54

Histogram of Stacking LoadsTest6 2,68

Histogram of Stacking LoadsTest6 3,82

Histogram of Stacking LoadsTest7 1,54

Histogram of Stacking LoadsTest7 2,68

Histogram of Stacking LoadsTest7 3,82

Histogram of Stacking LoadsTest9 1,54

Histogram of Stacking LoadsTest9 2,68

Histogram of Stacking LoadsTest9 3,82

Histogram of Stacking LoadsTest10 1,54

Histogram of Stacking LoadsTest10 2,68

Histogram of Stacking LoadsTest10 3,82

Histogram of Stacking LoadsTest12 1,54

Histogram of Stacking LoadsTest12 2,68

Histogram of Stacking LoadsTest12 3,82

Histogram of Stacking LoadsTest13 1,54

Histogram of Stacking LoadsTest13 2,68

Histogram of Stacking LoadsTest13 3,82

Histogram of Stacking LoadsTest14 1,54

Histogram of Stacking LoadsTest14 2,68

Histogram of Stacking LoadsTest14 3,82

Mann-Whitney Test and CI: Stacking LoadsTest1 1,54; Stacking LoadsTest3 1,54

```
                         N  Median
Stacking LoadsTest1 1,54  10  17,709
Stacking LoadsTest3 1,54  10  18,000


Point estimate for ETA1-ETA2 is -0,250
95,5 Percent CI for ETA1-ETA2 is (-0,834;1,084)
W = 100,5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,7624
The test is significant at 0,7614 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 2,68; Stacking LoadsTest3 2,68

```
                         N  Median
Stacking LoadsTest1 2,68  10  25,375
Stacking LoadsTest3 2,68  10  23,667


Point estimate for ETA1-ETA2 is 1,667
95,5 Percent CI for ETA1-ETA2 is (0,501;2,167)
W = 142,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0058
The test is significant at 0,0055 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 3,82; Stacking LoadsTest3 3,82

```
                         N  Median
Stacking LoadsTest1 3,82  10  37,833
Stacking LoadsTest3 3,82  10  34,333


Point estimate for ETA1-ETA2 is 3,167
95,5 Percent CI for ETA1-ETA2 is (2,333;4,417)
W = 154,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 1,54; Stacking LoadsTest4 1,54

```
                          N  Median
Stacking LoadsTest1 1,54  10  17,709
Stacking LoadsTest4 1,54  10  12,916


Point estimate for ETA1-ETA2 is 5,084
95,5 Percent CI for ETA1-ETA2 is (4,416;6,250)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 2,68; Stacking LoadsTest4 2,68

```
                          N  Median
Stacking LoadsTest1 2,68  10  25,375
Stacking LoadsTest4 2,68  10  22,913


Point estimate for ETA1-ETA2 is 2,500
95,5 Percent CI for ETA1-ETA2 is (1,280;3,083)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 3,82; Stacking LoadsTest4 3,82

```
                          N  Median
Stacking LoadsTest1 3,82  10  37,833
Stacking LoadsTest4 3,82  10  38,318


Point estimate for ETA1-ETA2 is -0,499
95,5 Percent CI for ETA1-ETA2 is (-1,666;0,084)
W = 79,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0539
```

Mann-Whitney Test and CI: Stacking LoadsTest1 1,54; Stacking LoadsTest7 1,54

```
                          N  Median
Stacking LoadsTest1 1,54  10  17,709
Stacking LoadsTest7 1,54   9  19,083


Point estimate for ETA1-ETA2 is -1,500
95,5 Percent CI for ETA1-ETA2 is (-2,083;0,000)
W = 77,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0662
The test is significant at 0,0656 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 2,68; Stacking LoadsTest7 2,68

```
                             N  Median
Stacking LoadsTest1 2,68  10  25,375
Stacking LoadsTest7 2,68   9  26,000


Point estimate for ETA1-ETA2 is -1,125
95,5 Percent CI for ETA1-ETA2 is (-2,166;0,000)
W = 74,5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0412
The test is significant at 0,0411 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 3,82; Stacking LoadsTest7 3,82

```
                             N  Median
Stacking LoadsTest1 3,82  10  37,833
Stacking LoadsTest7 3,82   9  39,833


Point estimate for ETA1-ETA2 is -2,291
95,5 Percent CI for ETA1-ETA2 is (-3,500;-1,250)
W = 59,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0009
```

Mann-Whitney Test and CI: Stacking LoadsTest4 1,54; Stacking LoadsTest6 1,54

```
                             N  Median
Stacking LoadsTest4 1,54  10  12,916
Stacking LoadsTest6 1,54  10   9,505


Point estimate for ETA1-ETA2 is 3,372
95,5 Percent CI for ETA1-ETA2 is (2,416;4,250)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 2,68; Stacking LoadsTest6 2,68

```
                             N  Median
Stacking LoadsTest4 2,68  10  22,913
Stacking LoadsTest6 2,68  10  17,500


Point estimate for ETA1-ETA2 is 5,167
95,5 Percent CI for ETA1-ETA2 is (4,499;5,834)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 3,82; Stacking LoadsTest6 3,82

```
                           N  Median
Stacking LoadsTest4 3,82  10  38,318
Stacking LoadsTest6 3,82  10  33,333


Point estimate for ETA1-ETA2 is 5,410
95,5 Percent CI for ETA1-ETA2 is (4,666;6,416)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 1,54; Stacking LoadsTest10 1,54

```
                            N  Median
Stacking LoadsTest4 1,54   10  12,916
Stacking LoadsTest10 1,54   6  12,958


Point estimate for ETA1-ETA2 is -0,083
95,5 Percent CI for ETA1-ETA2 is (-1,583;0,719)
W = 81,5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,7449
The test is significant at 0,7447 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 2,68; Stacking LoadsTest10 2,68

```
                            N  Median
Stacking LoadsTest4 2,68   10  22,913
Stacking LoadsTest10 2,68   6  22,500


Point estimate for ETA1-ETA2 is 0,375
95,5 Percent CI for ETA1-ETA2 is (-1,083;1,749)
W = 93,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,4159
The test is significant at 0,4156 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 3,82; Stacking LoadsTest10 3,82

```
                            N  Median
Stacking LoadsTest1 3,82   10  37,833
Stacking LoadsTest10 3,82   6  41,708


Point estimate for ETA1-ETA2 is -4,000
95,5 Percent CI for ETA1-ETA2 is (-5,250;-2,333)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
The test is significant at 0,0014 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 1,54; Stacking LoadsTest9 1,54

```
                          N  Median
Stacking LoadsTest7 1,54  9  19,083
Stacking LoadsTest9 1,54  8  16,167


Point estimate for ETA1-ETA2 is 2,916
95,1 Percent CI for ETA1-ETA2 is (2,583;4,832)
W = 117,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0006
The test is significant at 0,0006 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 2,68; Stacking LoadsTest9 2,68

```
                          N  Median
Stacking LoadsTest7 2,68  9  26,000
Stacking LoadsTest9 2,68  8  22,500


Point estimate for ETA1-ETA2 is 3,542
95,1 Percent CI for ETA1-ETA2 is (3,164;4,998)
W = 117,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0006
The test is significant at 0,0006 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 3,82; Stacking LoadsTest9 3,82

```
                          N  Median
Stacking LoadsTest7 3,82  9  39,833
Stacking LoadsTest9 3,82  8  36,500


Point estimate for ETA1-ETA2 is 3,583
95,1 Percent CI for ETA1-ETA2 is (2,667;4,500)
W = 117,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0006
The test is significant at 0,0006 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 1,54; Stacking LoadsTest12 1,54

```
                            N  Median
Stacking LoadsTest10 1,54   6  12,958
Stacking LoadsTest12 1,54  10   9,666


Point estimate for ETA1-ETA2 is 3,250
95,5 Percent CI for ETA1-ETA2 is (2,001;4,667)
W = 80,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0020
The test is significant at 0,0020 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 2,68; Stacking LoadsTest12 2,68

```
                             N  Median
Stacking LoadsTest10 2,68   6  22,500
Stacking LoadsTest12 2,68  10  16,833


Point estimate for ETA1-ETA2 is 5,583
95,5 Percent CI for ETA1-ETA2 is (4,082;6,833)
W = 81,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
The test is significant at 0,0014 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 3,82; Stacking LoadsTest12 3,82

```
                             N  Median
Stacking LoadsTest10 3,82   6  41,708
Stacking LoadsTest12 3,82  10  37,499


Point estimate for ETA1-ETA2 is 4,375
95,5 Percent CI for ETA1-ETA2 is (2,751;5,417)
W = 81,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
The test is significant at 0,0014 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 1,54; Stacking LoadsTest10 1,54

```
                            N  Median
Stacking LoadsTest7 1,54   9  19,083
Stacking LoadsTest10 1,54  6  12,958


Point estimate for ETA1-ETA2 is 6,125
96,1 Percent CI for ETA1-ETA2 is (4,917;7,500)
W = 99,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0018
The test is significant at 0,0018 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 2,68; Stacking LoadsTest10 2,68

```
                            N  Median
Stacking LoadsTest7 2,68   9  26,000
Stacking LoadsTest10 2,68  6  22,500


Point estimate for ETA1-ETA2 is 3,667
96,1 Percent CI for ETA1-ETA2 is (2,249;5,251)
W = 90,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0392
```

Mann-Whitney Test and CI: Stacking LoadsTest7 3,82; Stacking LoadsTest10 3,82

```
                          N  Median
Stacking LoadsTest7 3,82   9  39,833
Stacking LoadsTest10 3,82  6  41,708


Point estimate for ETA1-ETA2 is -1,541
96,1 Percent CI for ETA1-ETA2 is (-2,999;-0,084)
W = 54,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0392
The test is significant at 0,0390 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest9 1,54; Stacking LoadsTest12 1,54

```
                           N  Median
Stacking LoadsTest9 1,54    8  16,167
Stacking LoadsTest12 1,54  10   9,666


Point estimate for ETA1-ETA2 is 6,335
95,4 Percent CI for ETA1-ETA2 is (5,666;7,001)
W = 116,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0004
The test is significant at 0,0004 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest9 2,68; Stacking LoadsTest12 2,68

```
                           N  Median
Stacking LoadsTest9 2,68    8  22,500
Stacking LoadsTest12 2,68  10  16,833


Point estimate for ETA1-ETA2 is 5,667
95,4 Percent CI for ETA1-ETA2 is (5,000;6,002)
W = 116,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0004
The test is significant at 0,0004 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest9 3,82; Stacking LoadsTest12 3,82

```
                           N  Median
Stacking LoadsTest9 3,82    8  36,500
Stacking LoadsTest12 3,82  10  37,499


Point estimate for ETA1-ETA2 is -0,999
95,4 Percent CI for ETA1-ETA2 is (-1,667;-0,333)
W = 49,5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0209
The test is significant at 0,0206 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest6 1,54; Stacking LoadsTest14 1,54

```
                           N  Median
Stacking LoadsTest6 1,54   10   9,505
Stacking LoadsTest14 1,54   3  15,000


Point estimate for ETA1-ETA2 is -5,661
96,5 Percent CI for ETA1-ETA2 is (-7,332;-4,332)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0142
The test is significant at 0,0141 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest6 2,68; Stacking LoadsTest14 2,68

```
                           N  Median
Stacking LoadsTest6 2,68   10  17,500
Stacking LoadsTest14 2,68   3  26,666


Point estimate for ETA1-ETA2 is -9,000
96,5 Percent CI for ETA1-ETA2 is (-10,333;-8,000)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0142
The test is significant at 0,0141 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest6 3,82; Stacking LoadsTest14 3,82

```
                           N  Median
Stacking LoadsTest6 3,82   10  33,333
Stacking LoadsTest14 3,82   3  36,333


Point estimate for ETA1-ETA2 is -2,999
96,5 Percent CI for ETA1-ETA2 is (-5,323;-1,666)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0142
The test is significant at 0,0140 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest12 1,54; Stacking LoadsTest13 1,54

```
                           N  Median
Stacking LoadsTest12 1,54  10   9,666
Stacking LoadsTest13 1,54   3  13,000


Point estimate for ETA1-ETA2 is -3,001
96,5 Percent CI for ETA1-ETA2 is (-4,667;-1,332)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0142
```

```
The test is significant at 0,0140 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest12 2,68; Stacking LoadsTest13 2,68

```
                             N  Median
Stacking LoadsTest12 2,68  10  16,833
Stacking LoadsTest13 2,68   3  25,666


Point estimate for ETA1-ETA2 is -8,833
96,5 Percent CI for ETA1-ETA2 is (-11,334;-6,335)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0142
The test is significant at 0,0140 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest12 3,82; Stacking LoadsTest13 3,82

```
                             N  Median
Stacking LoadsTest12 3,82  10  37,499
Stacking LoadsTest13 3,82   3  36,999


Point estimate for ETA1-ETA2 is 0,666
96,5 Percent CI for ETA1-ETA2 is (-0,668;2,665)
W = 78,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,2049
The test is significant at 0,2043 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest13 1,54; Stacking LoadsTest14 1,54

```
                            N  Median
Stacking LoadsTest13 1,54  3  13,000
Stacking LoadsTest14 1,54  3  15,000


Point estimate for ETA1-ETA2 is -2,000
91,9 Percent CI for ETA1-ETA2 is (-4,333;-0,333)
W = 6,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0809
```

Mann-Whitney Test and CI: Stacking LoadsTest13 2,68; Stacking LoadsTest14 2,68

```
                            N  Median
Stacking LoadsTest13 2,68  3  25,666
Stacking LoadsTest14 2,68  3  26,666


Point estimate for ETA1-ETA2 is -1,000
91,9 Percent CI for ETA1-ETA2 is (-3,332;1,333)
W = 9,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,6625
```

Mann-Whitney Test and CI: Stacking LoadsTest13 3,82; Stacking LoadsTest14 3,82

```
                          N  Median
Stacking LoadsTest13 3,82  3  36,999
Stacking LoadsTest14 3,82  3  36,333


Point estimate for ETA1-ETA2 is 0,667
91,9 Percent CI for ETA1-ETA2 is (-0,998;1,335)
W = 12,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,6625
```

Mann-Whitney Test and CI: Stacking LoadsTest1 1,54; Stacking LoadsTest12 1,54

```
                           N  Median
Stacking LoadsTest1 1,54   10  17,709
Stacking LoadsTest12 1,54  10   9,666


Point estimate for ETA1-ETA2 is 8,084
95,5 Percent CI for ETA1-ETA2 is (7,418;9,417)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 2,68; Stacking LoadsTest12 2,68

```
                           N  Median
Stacking LoadsTest1 2,68   10  25,375
Stacking LoadsTest12 2,68  10  16,833


Point estimate for ETA1-ETA2 is 8,292
95,5 Percent CI for ETA1-ETA2 is (7,250;9,166)
W = 155,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0002
The test is significant at 0,0002 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest1 3,82; Stacking LoadsTest12 3,82

```
                           N  Median
Stacking LoadsTest1 3,82   10  37,833
Stacking LoadsTest12 3,82  10  37,499


Point estimate for ETA1-ETA2 is 0,416
95,5 Percent CI for ETA1-ETA2 is (-0,666;1,084)
W = 118,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,3447
The test is significant at 0,3445 (adjusted for ties)
```

16.08.2012 13:31:23

```
Welcome to Minitab, press F1 for help.
Retrieving project from file: 'M:\THESIS\GOOGLE DRIVE\MINITAB.MPJ'
```

Histogram of Stacking LoadsTest10 1,54

Histogram of Stacking LoadsTest10 2,68

Histogram of Stacking LoadsTest10 3,82

Mann-Whitney Test and CI: Stacking LoadsTest4 1,54; Stacking LoadsTest10 1,54

```
                             N  Median
Stacking LoadsTest4 1,54    10  12,916
Stacking LoadsTest10 1,54    6  13,083


Point estimate for ETA1-ETA2 is -0,389
95,5 Percent CI for ETA1-ETA2 is (-1,583;0,585)
W = 83,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,8708
```

Mann-Whitney Test and CI: Stacking LoadsTest4 2,68; Stacking LoadsTest10 2,68

```
                             N  Median
Stacking LoadsTest4 2,68    10  22,913
Stacking LoadsTest10 2,68    6  22,625


Point estimate for ETA1-ETA2 is 0,042
95,5 Percent CI for ETA1-ETA2 is (-9,278;1,804)
W = 87,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,8708
The test is significant at 0,8707 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 3,82; Stacking LoadsTest10 3,82

```
                             N  Median
Stacking LoadsTest4 3,82    10  38,318
Stacking LoadsTest10 3,82    6  41,458
```

```
Point estimate for ETA1-ETA2 is -3,125
95,5 Percent CI for ETA1-ETA2 is (-4,416;-1,756)
W = 55,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
```

Mann-Whitney Test and CI: Stacking LoadsTest7 1,54; Stacking LoadsTest10 1,54

```
                           N  Median
Stacking LoadsTest7 1,54   9  19,083
Stacking LoadsTest10 1,54  6  13,083


Point estimate for ETA1-ETA2 is 6,168
96,1 Percent CI for ETA1-ETA2 is (5,167;7,751)
W = 99,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0018
The test is significant at 0,0018 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 2,68; Stacking LoadsTest10 2,68

```
                           N  Median
Stacking LoadsTest7 2,68   9  26,000
Stacking LoadsTest10 2,68  6  22,625


Point estimate for ETA1-ETA2 is 3,459
96,1 Percent CI for ETA1-ETA2 is (-6,082;5,250)
W = 81,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,3165
```

Mann-Whitney Test and CI: Stacking LoadsTest7 3,82; Stacking LoadsTest10 3,82

```
                           N  Median
Stacking LoadsTest7 3,82   9  39,833
Stacking LoadsTest10 3,82  6  41,458


Point estimate for ETA1-ETA2 is -1,536
96,1 Percent CI for ETA1-ETA2 is (-3,084;-0,000)
W = 54,5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0451
The test is significant at 0,0449 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 1,54; Stacking LoadsTest12 1,54

```
                            N  Median
Stacking LoadsTest10 1,54   6  13,083
Stacking LoadsTest12 1,54  10   9,666
```

```
Point estimate for ETA1-ETA2 is 3,333
95,5 Percent CI for ETA1-ETA2 is (1,916;4,333)
W = 80,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0020
The test is significant at 0,0020 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 2,68; Stacking LoadsTest12 2,68

```
                            N  Median
Stacking LoadsTest10 2,68   6  22,625
Stacking LoadsTest12 2,68  10  16,833


Point estimate for ETA1-ETA2 is 5,750
95,5 Percent CI for ETA1-ETA2 is (4,251;15,252)
W = 81,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
The test is significant at 0,0014 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest10 3,82; Stacking LoadsTest12 3,82

```
                            N  Median
Stacking LoadsTest10 3,82   6  41,458
Stacking LoadsTest12 3,82  10  37,499


Point estimate for ETA1-ETA2 is 4,125
95,5 Percent CI for ETA1-ETA2 is (2,751;5,416)
W = 81,0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0,0014
The test is significant at 0,0014 (adjusted for ties)
```

8/25/2012 1:27:44 PM

```
Welcome to Minitab, press F1 for help.
Retrieving project from file: 'C:\USERS\ZACK\GOOGLE DRIVE\DATA\MINITAB.MPJ'
```

27.08.2012 11:05:45

```
Welcome to Minitab, press F1 for help.
Retrieving project from file: 'M:\THESIS\GOOGLE
DRIVE\DATA\MINITAB[CONFLICT].MPJ'

Histogram of Stacking LoadsTest10 3,82
```

10/10/2012 9:20:08 AM

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Retrieving project from file: 'C:\USERS\KAPMETA\DOWNLOADS\MINITAB (2)
(1).MPJ'
```

Histogram of Stacking LoadsTest10 1,54

Histogram of Stacking LoadsTest10 2,68

Histogram of Stacking LoadsTest10 3,82

Mann-Whitney Test and CI: Stacking LoadsTest4 1,54, Stacking LoadsTest10 1,54

```
                           N  Median
Stacking LoadsTest4 1,54   10  12.916
Stacking LoadsTest10 1,54   6  11.334


Point estimate for ETA1-ETA2 is 1.499
95.5 Percent CI for ETA1-ETA2 is (0.500,1.750)
W = 106.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0262
```

Mann-Whitney Test and CI: Stacking LoadsTest4 2,68, Stacking LoadsTest10 2,68

```
                           N  Median
Stacking LoadsTest4 2,68   10  22.913
Stacking LoadsTest10 2,68   6  32.667


Point estimate for ETA1-ETA2 is -9.750
95.5 Percent CI for ETA1-ETA2 is (-10.417,-8.667)
W = 55.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0014
The test is significant at 0.0014 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest4 3,82, Stacking LoadsTest10 3,82

```
                           N  Median
Stacking LoadsTest4 3,82   10  38.318
Stacking LoadsTest10 3,82   6  40.584


Point estimate for ETA1-ETA2 is -2.307
95.5 Percent CI for ETA1-ETA2 is (-4.617,-1.749)
W = 55.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0014
```

Mann-Whitney Test and CI: Stacking LoadsTest7 1,54, Stacking LoadsTest10 1,54

```
                          N  Median
Stacking LoadsTest7 1,54   9  19.083
```

```
Stacking LoadsTest10 1,54  6  11.334


Point estimate for ETA1-ETA2 is 7.667
96.1 Percent CI for ETA1-ETA2 is (6.917,9.581)
W = 99.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0018
The test is significant at 0.0018 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 2,68, Stacking LoadsTest10 2,68

```
                           N  Median
Stacking LoadsTest7 2,68   9  26.000
Stacking LoadsTest10 2,68  6  32.667


Point estimate for ETA1-ETA2 is -6.167
96.1 Percent CI for ETA1-ETA2 is (-7.333,-5.000)
W = 45.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0018
The test is significant at 0.0018 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest7 3,82, Stacking LoadsTest10 3,82

```
                           N  Median
Stacking LoadsTest7 3,82   9  39.833
Stacking LoadsTest10 3,82  6  40.584


Point estimate for ETA1-ETA2 is -1.017
96.1 Percent CI for ETA1-ETA2 is (-2.950,0.417)
W = 56.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0677
```

Mann-Whitney Test and CI: Stacking LoadsTest12 1,54, Stacking LoadsTest10 1,54

```
                            N  Median
Stacking LoadsTest12 1,54  10   9.666
Stacking LoadsTest10 1,54   6  11.334


Point estimate for ETA1-ETA2 is -1.834
95.5 Percent CI for ETA1-ETA2 is (-2.252,-0.914)
W = 60.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0079
The test is significant at 0.0078 (adjusted for ties)
```

Mann-Whitney Test and CI: Stacking LoadsTest12 2,68, Stacking LoadsTest10 2,68

```
                            N  Median
Stacking LoadsTest12 2,68  10  16.833
```

```
Stacking LoadsTest10 2,68   6  32.667


Point estimate for ETA1-ETA2 is -15.542
95.5 Percent CI for ETA1-ETA2 is (-16.417,-14.500)
W = 55.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0014
The test is significant at 0.0013 (adjusted for ties)
```

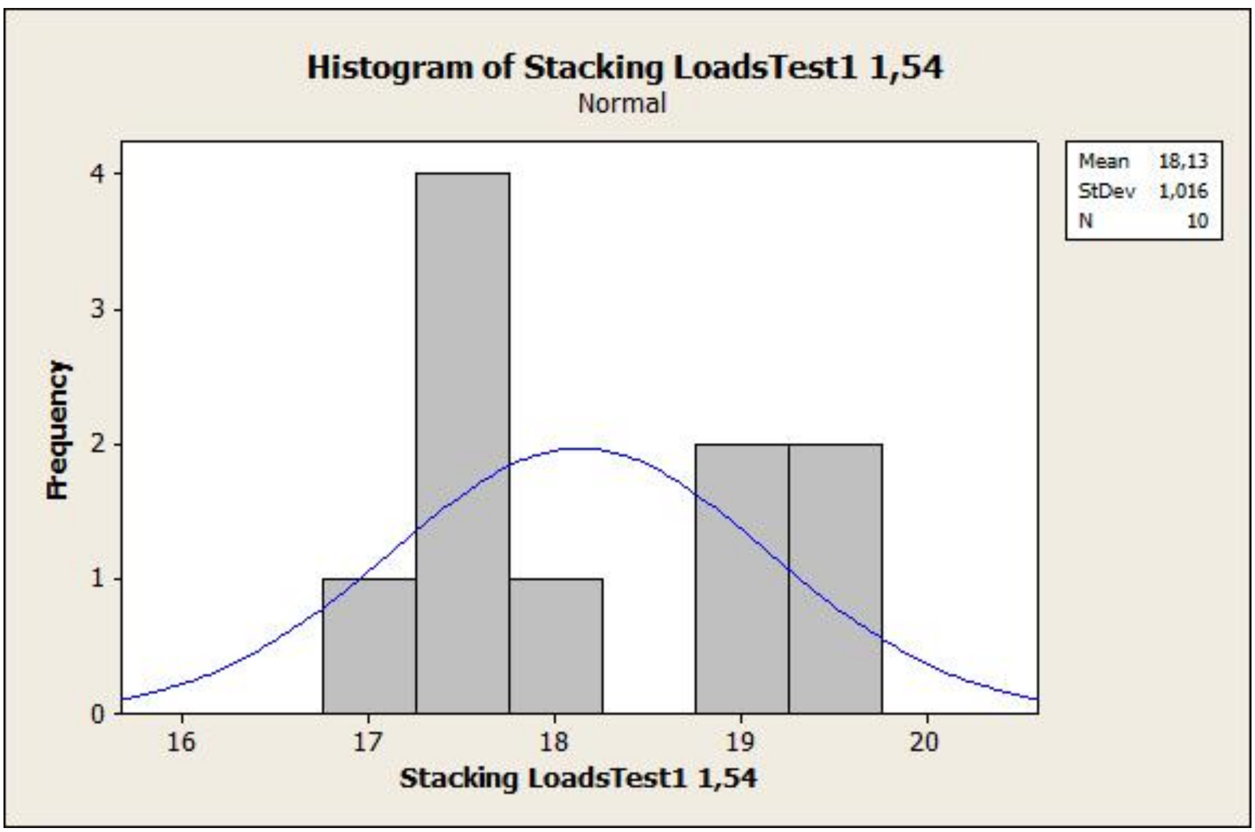
Mann-Whitney Test and CI: Stacking LoadsTest12 3,82, Stacking LoadsTest10 3,82

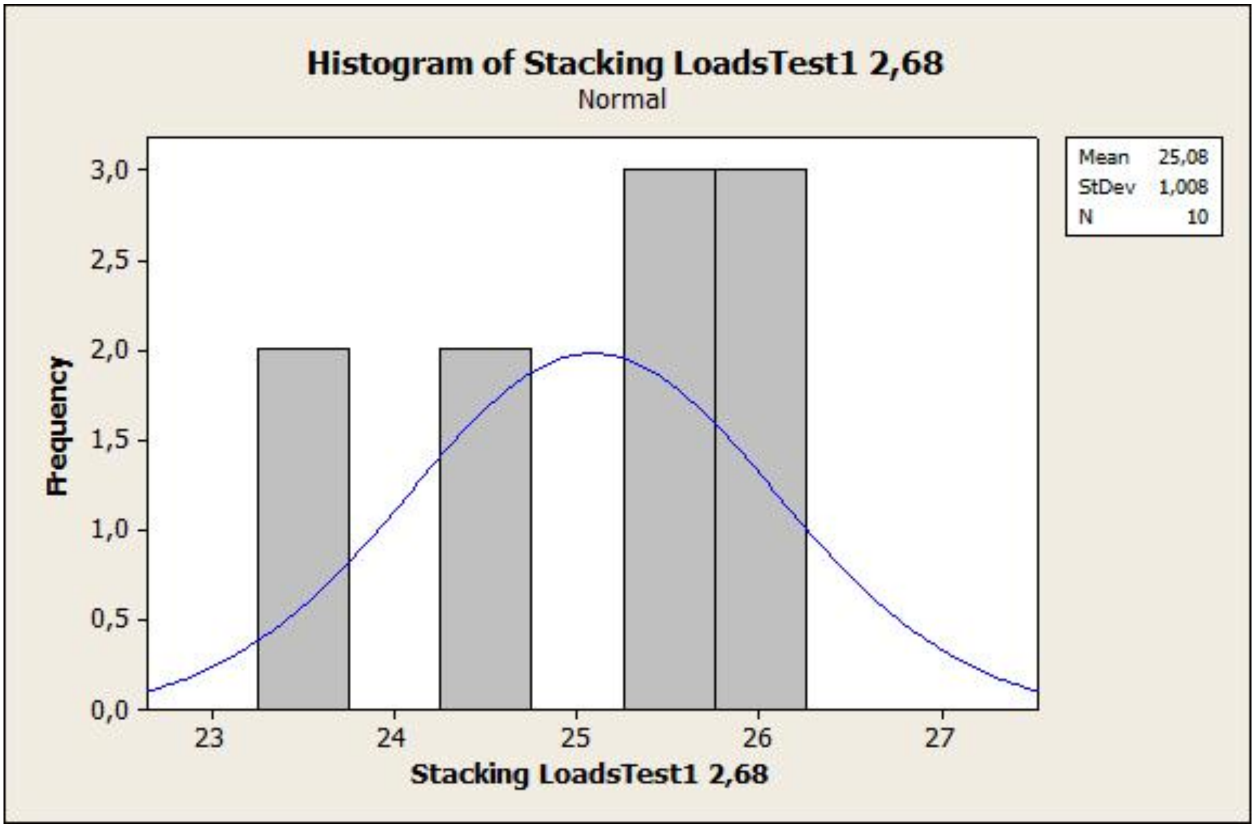
```
                            N  Median
Stacking LoadsTest12 3,82  10  37.499
Stacking LoadsTest10 3,82   6  40.584

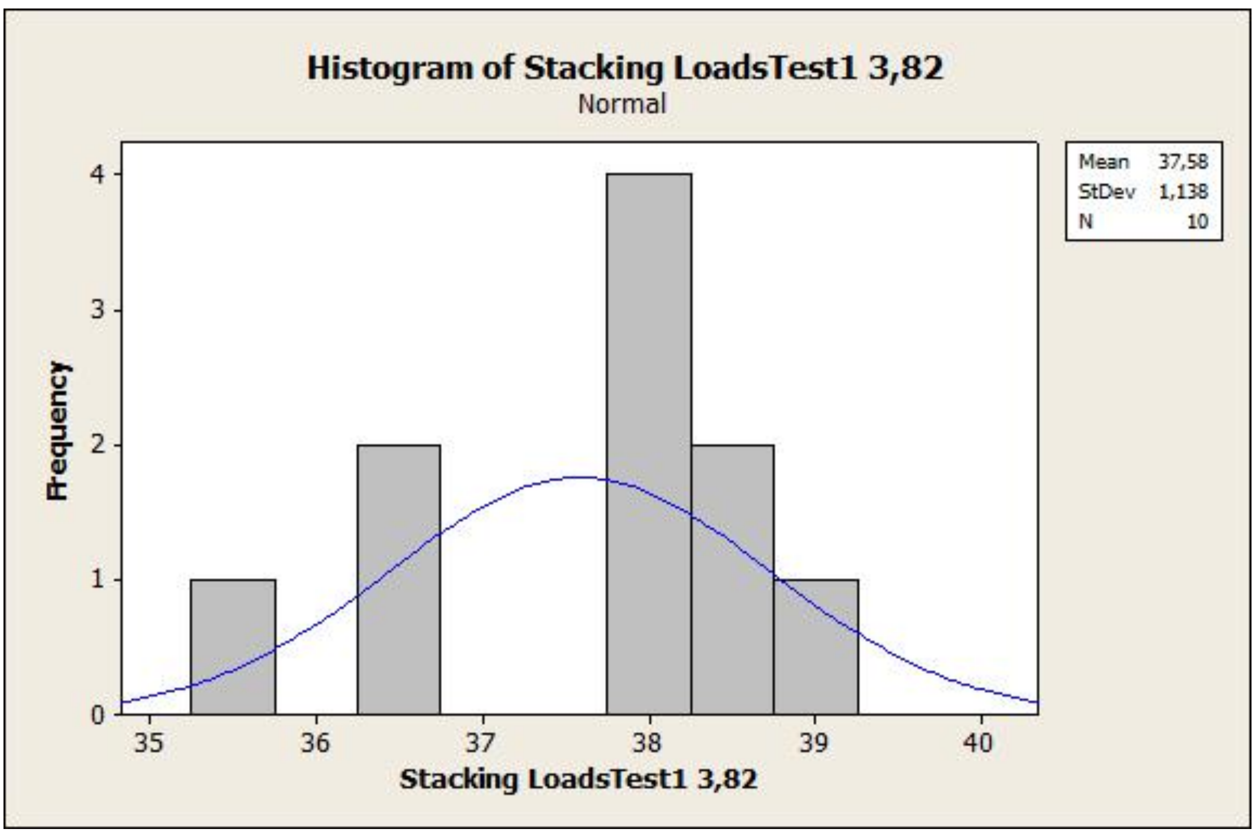

Point estimate for ETA1-ETA2 is -3.583
95.5 Percent CI for ETA1-ETA2 is (-5.417,-2.583)
W = 55.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0014
The test is significant at 0.0014 (adjusted for ties)
```

9.2. Histograms

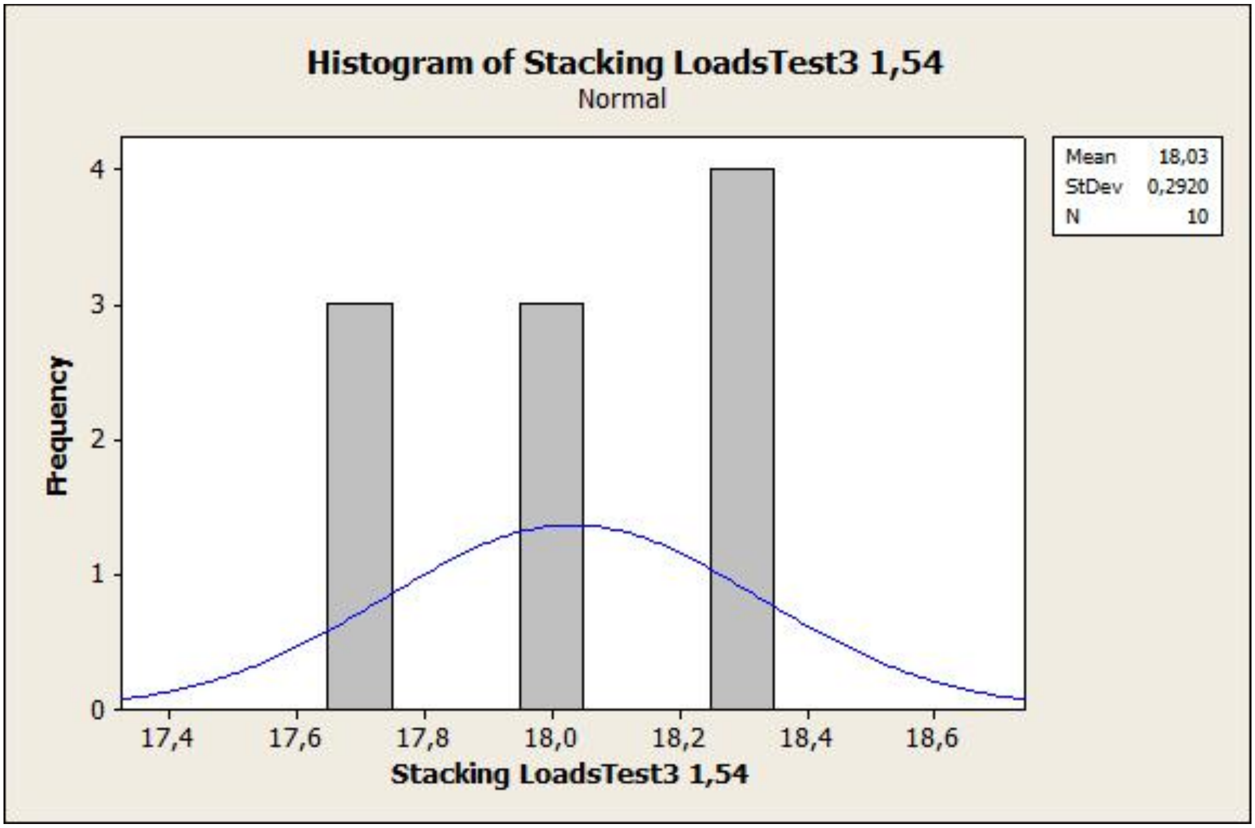
9.2.1. Condition 1

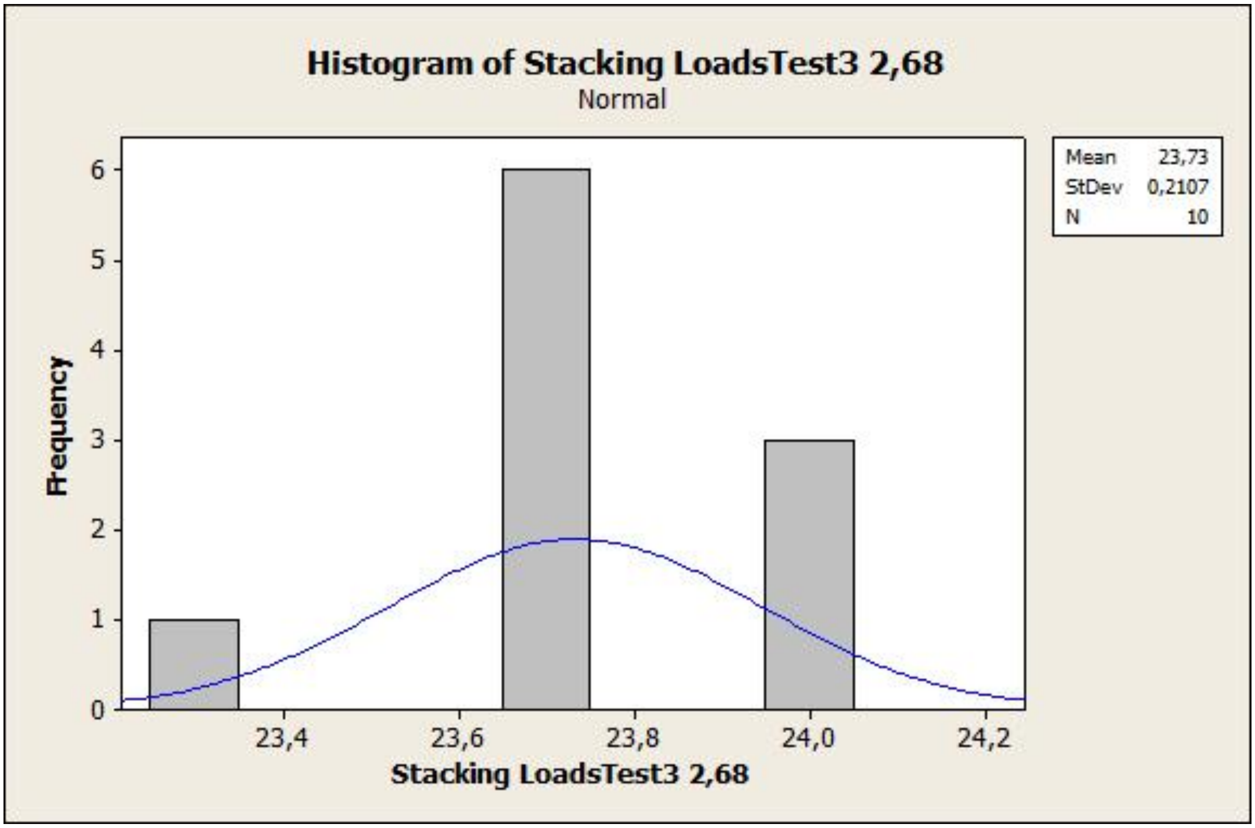


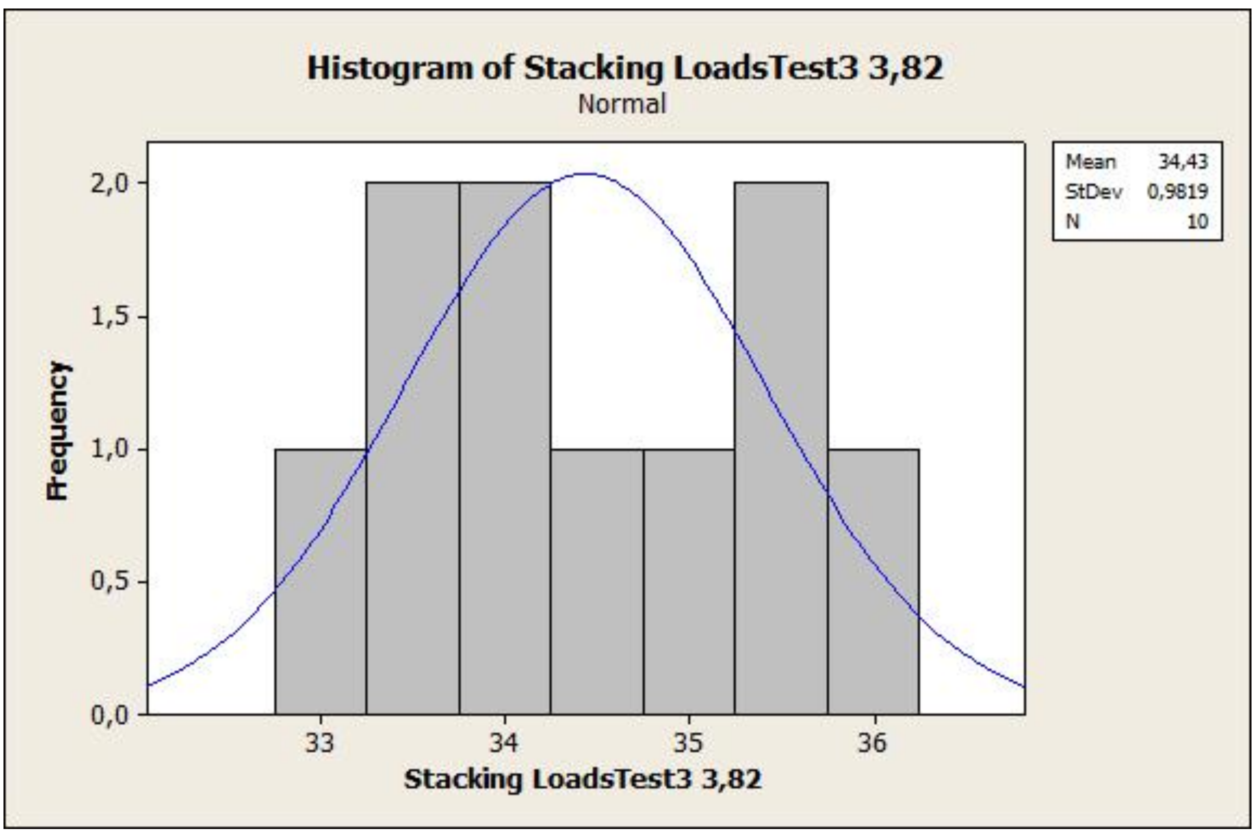

Histogram of Stacking LoadsTest1 2,68
Normal
Mean 25,08
StDev 1,008
N 10
Frequency
3,0
2,5
2,0
1,5
1,0
0,5
0,0
23
24
25
26
27
Stacking LoadsTest1 2,68


Histogram of Stacking LoadsTest1 3,82
Normal
Mean 37,58
StDev 1,138
N 10
Frequency
4
3
2
1
0
35
36
37
38
39
40
Stacking LoadsTest1 3,82

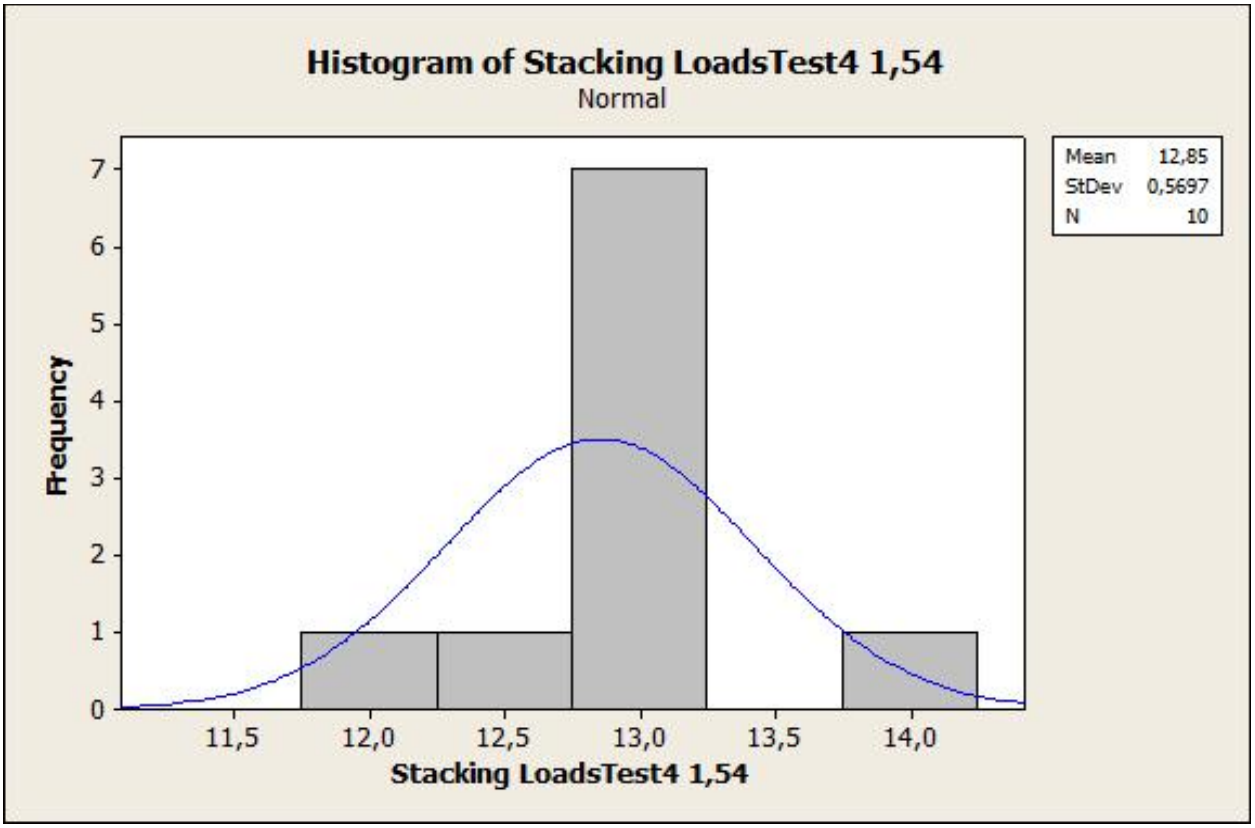
9.2.2. Condition 3

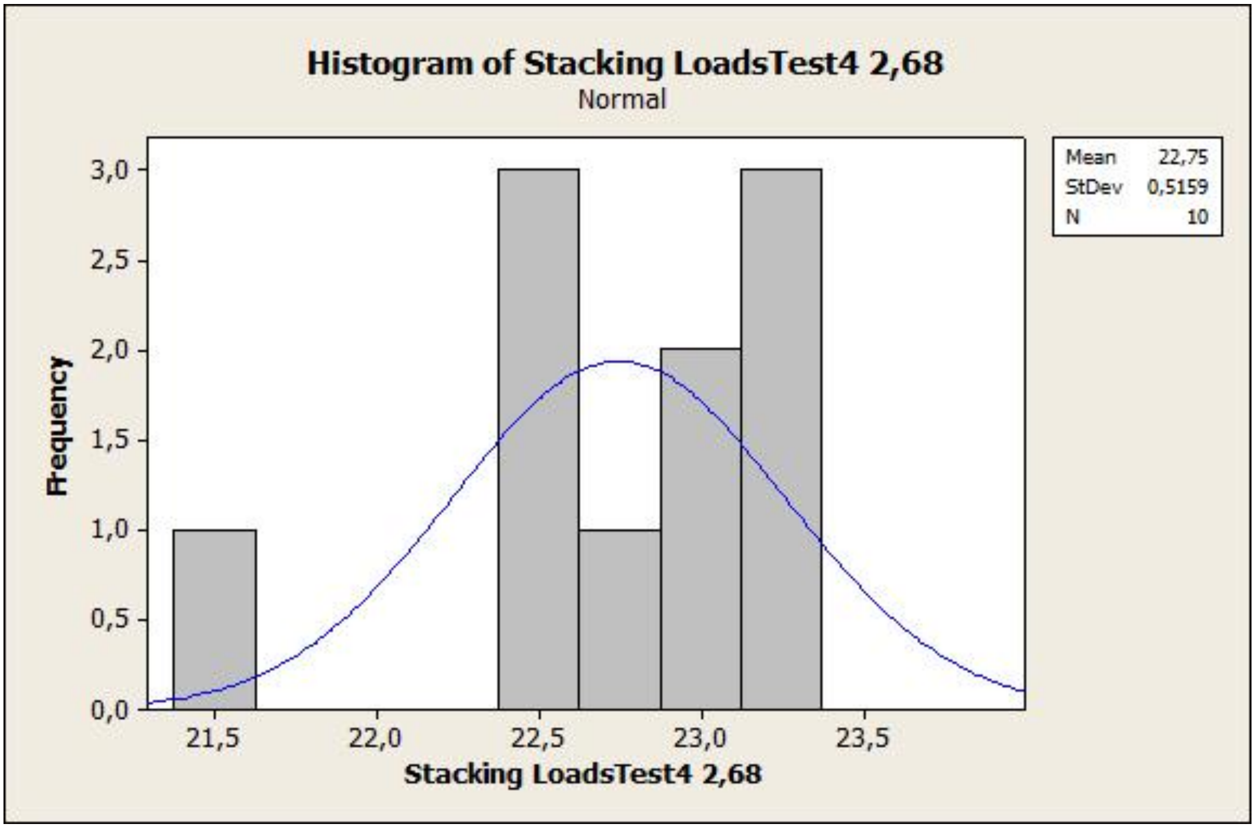


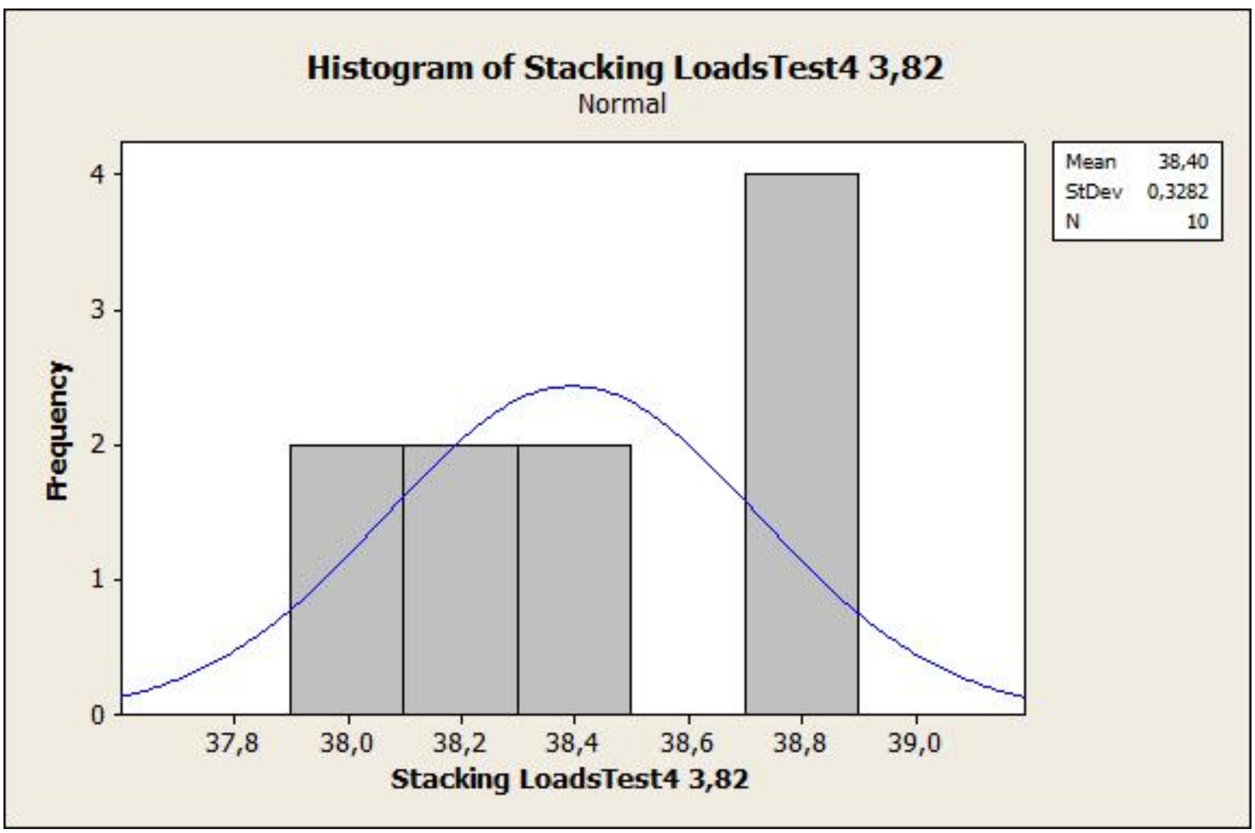

Histogram of Stacking LoadsTest3 2,68
Normal
Mean 23,73
StDev 0,2107
N 10
Frequency
0
1
2
3
4
5
6
23,4
23,6
23,8
24,0
24,2
Stacking LoadsTest3 2,68


Histogram of Stacking LoadsTest3 3,82
Normal
Mean 34,43
StDev 0,9819
N 10
Frequency
0,0
0,5
1,0
1,5
2,0
33
34
35
36
Stacking LoadsTest3 3,82

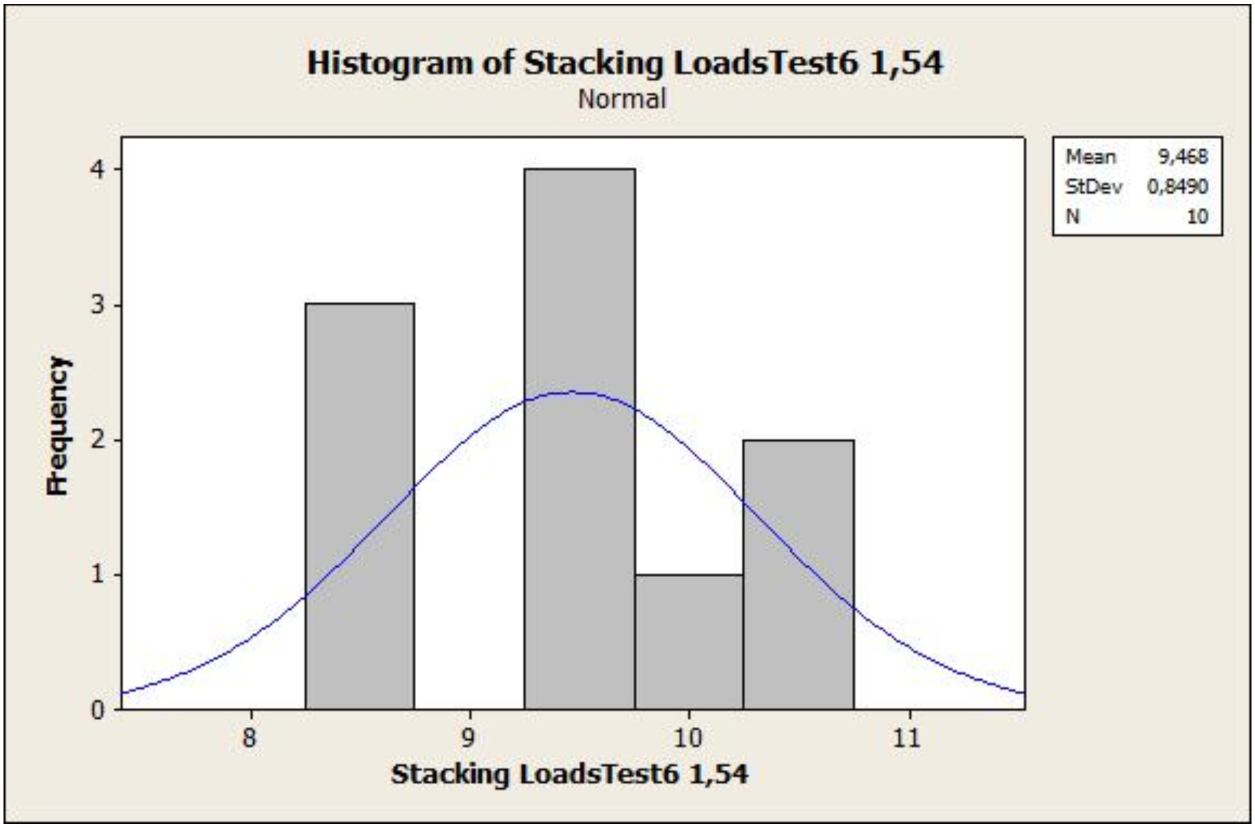
9.2.3. Condition 4

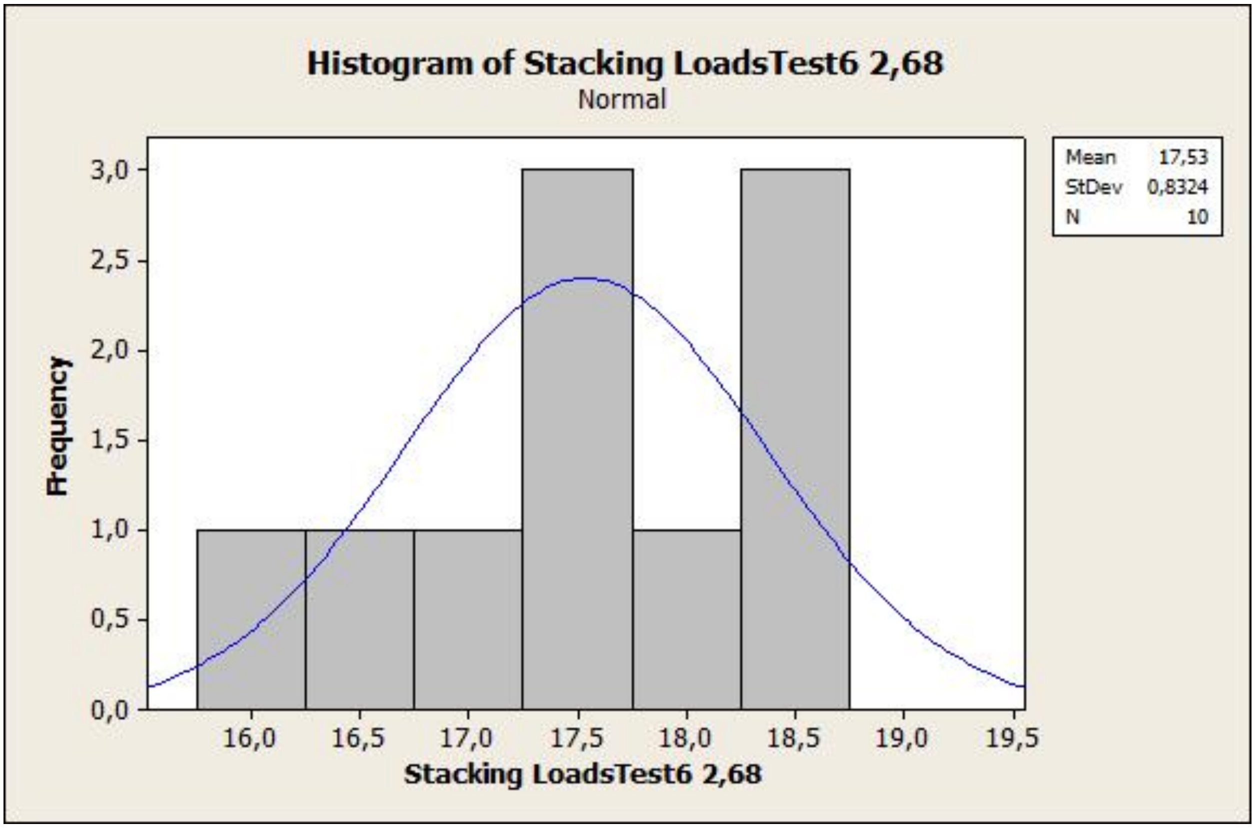


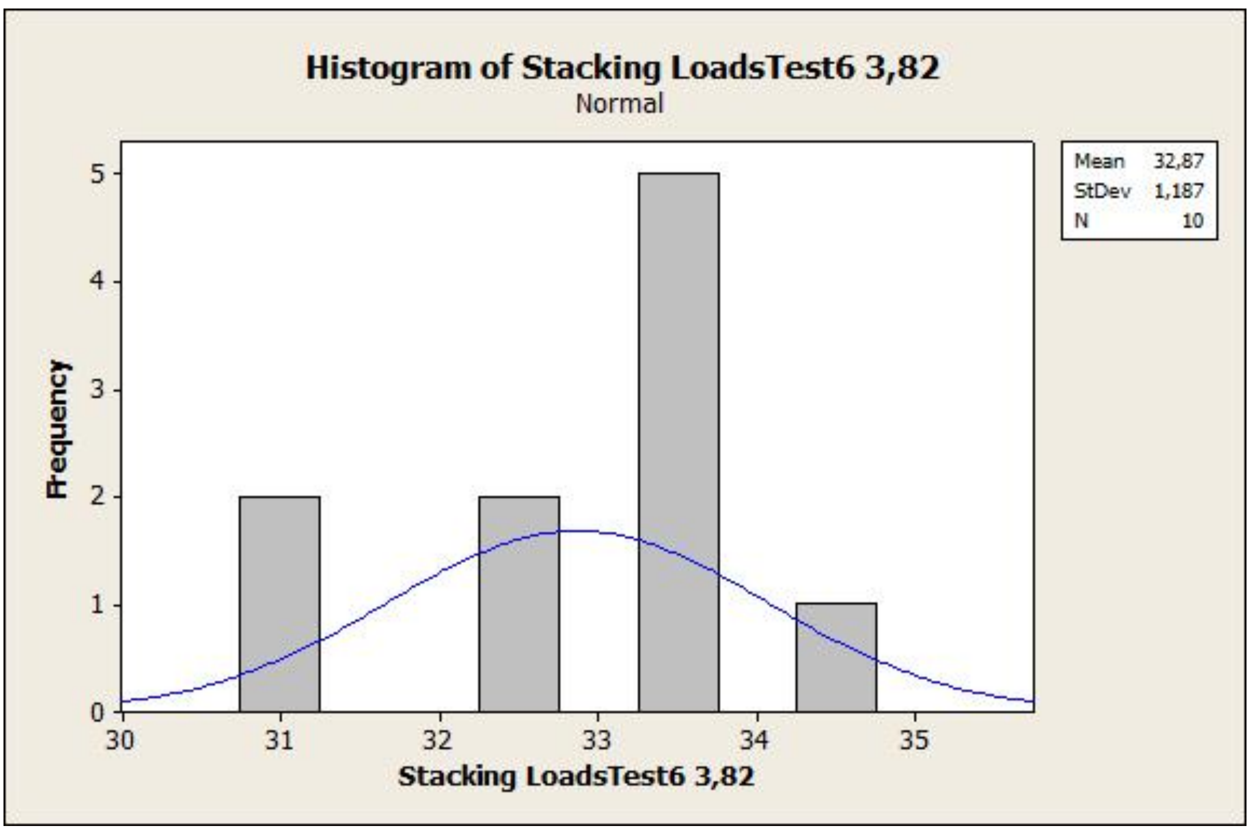

Histogram of Stacking LoadsTest4 2,68
Normal
Mean 22,75
StDev 0,5159
N 10
Frequency
3,0
2,5
2,0
1,5
1,0
0,5
0,0
21,5
22,0
22,5
23,0
23,5
Stacking LoadsTest4 2,68


Histogram of Stacking LoadsTest4 3,82
Normal
Mean 38,40
StDev 0,3282
N 10
Frequency
4
3
2
1
0
37,8
38,0
38,2
38,4
38,6
38,8
39,0
Stacking LoadsTest4 3,82

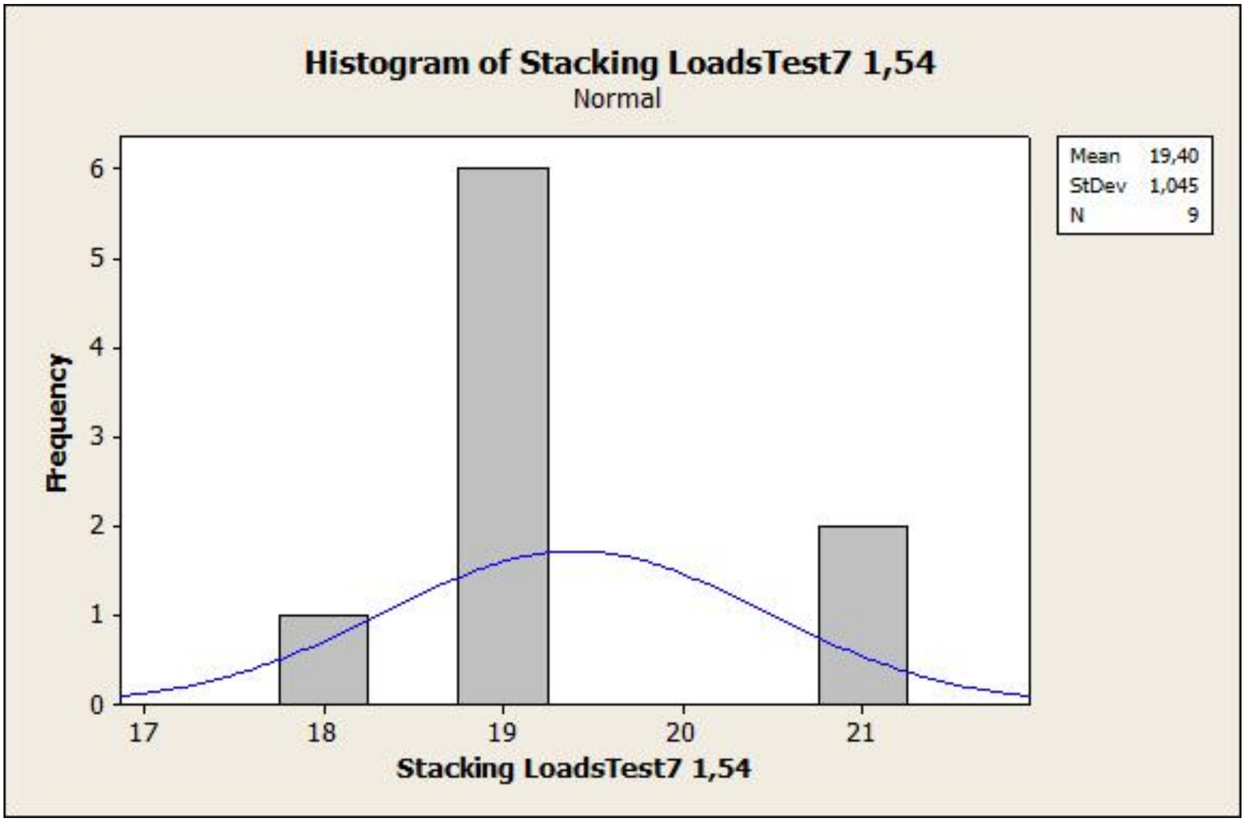
9.2.4. Condition 6

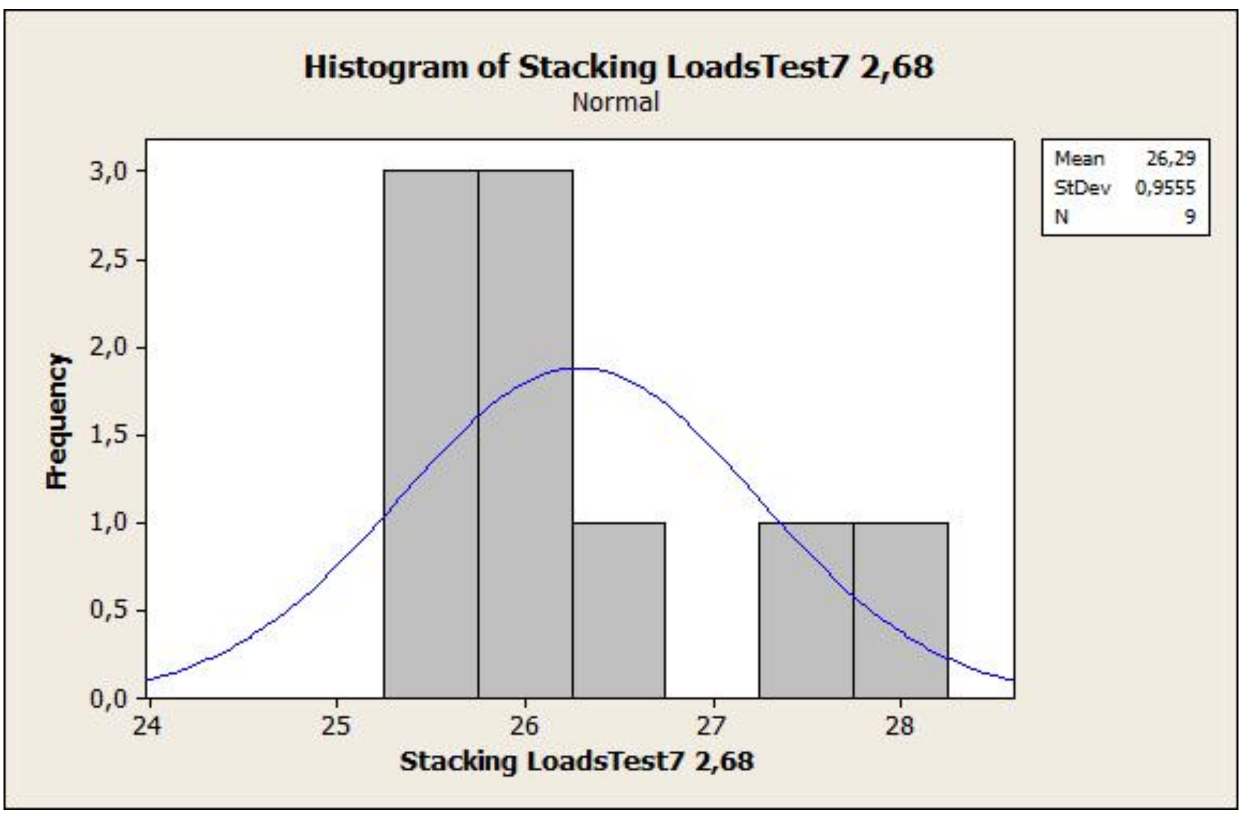


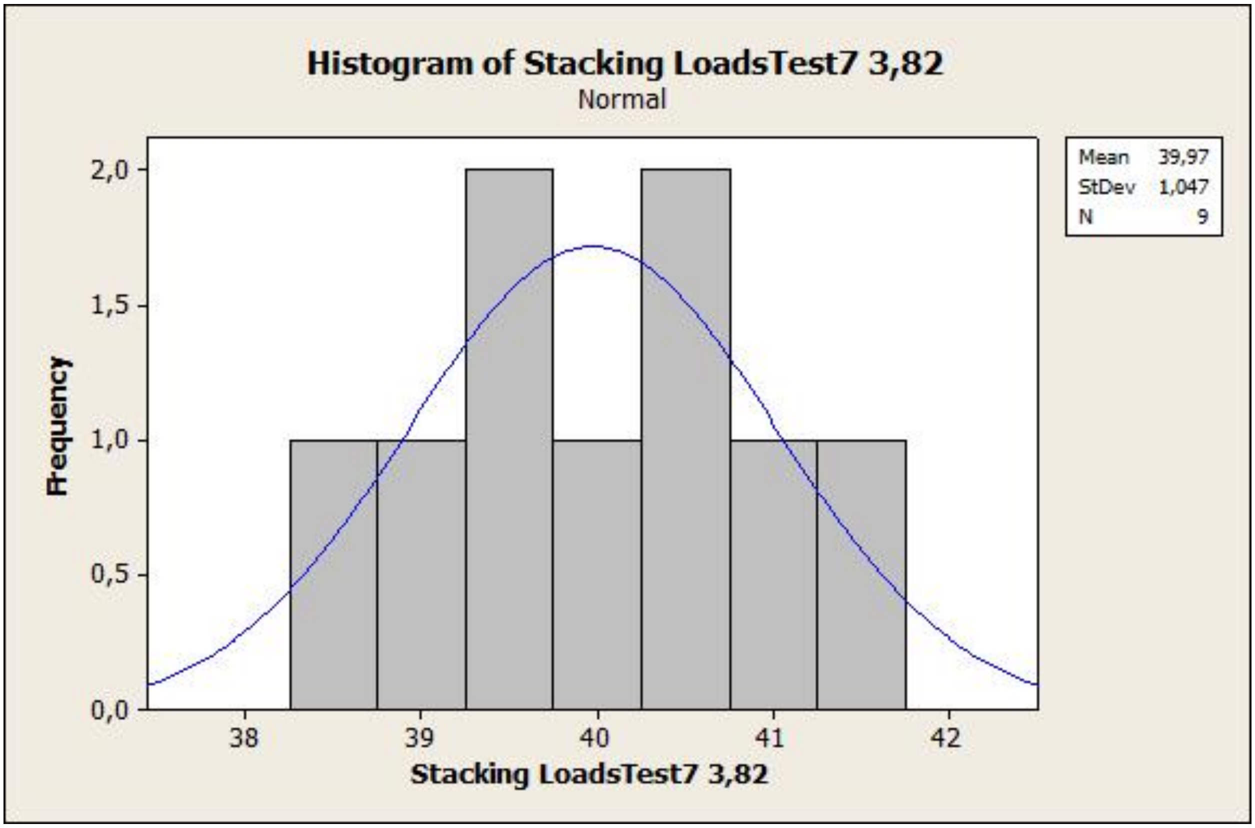

Histogram of Stacking LoadsTest6 2,68
Normal
Mean 17,53
StDev 0,8324
N 10
Frequency
3,0
2,5
2,0
1,5
1,0
0,5
0,0
16,0
16,5
17,0
17,5
18,0
18,5
19,0
19,5
Stacking LoadsTest6 2,68


Histogram of Stacking LoadsTest6 3,82
Normal
Mean 32,87
StDev 1,187
N 10
Frequency
5
4
3
2
1
0
30
31
32
33
34
35
Stacking LoadsTest6 3,82

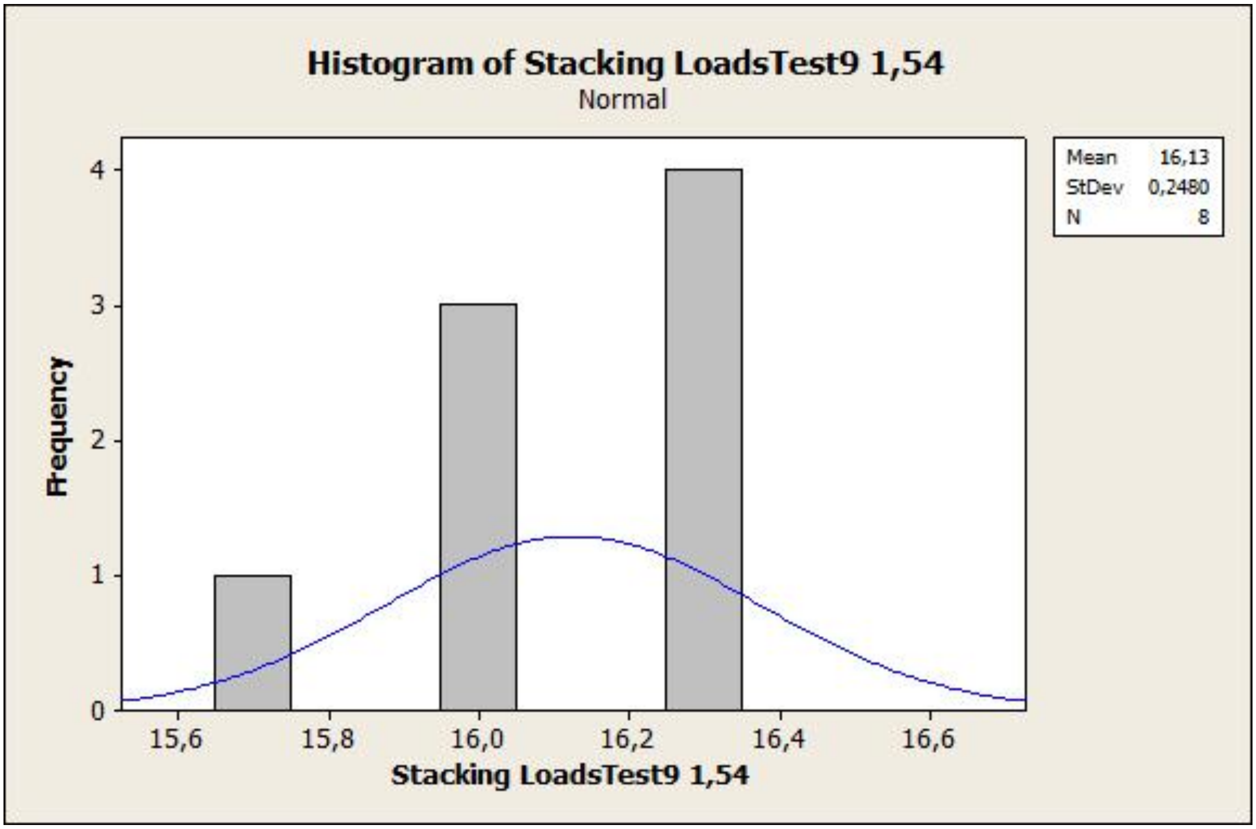
9.2.5. Condition 7

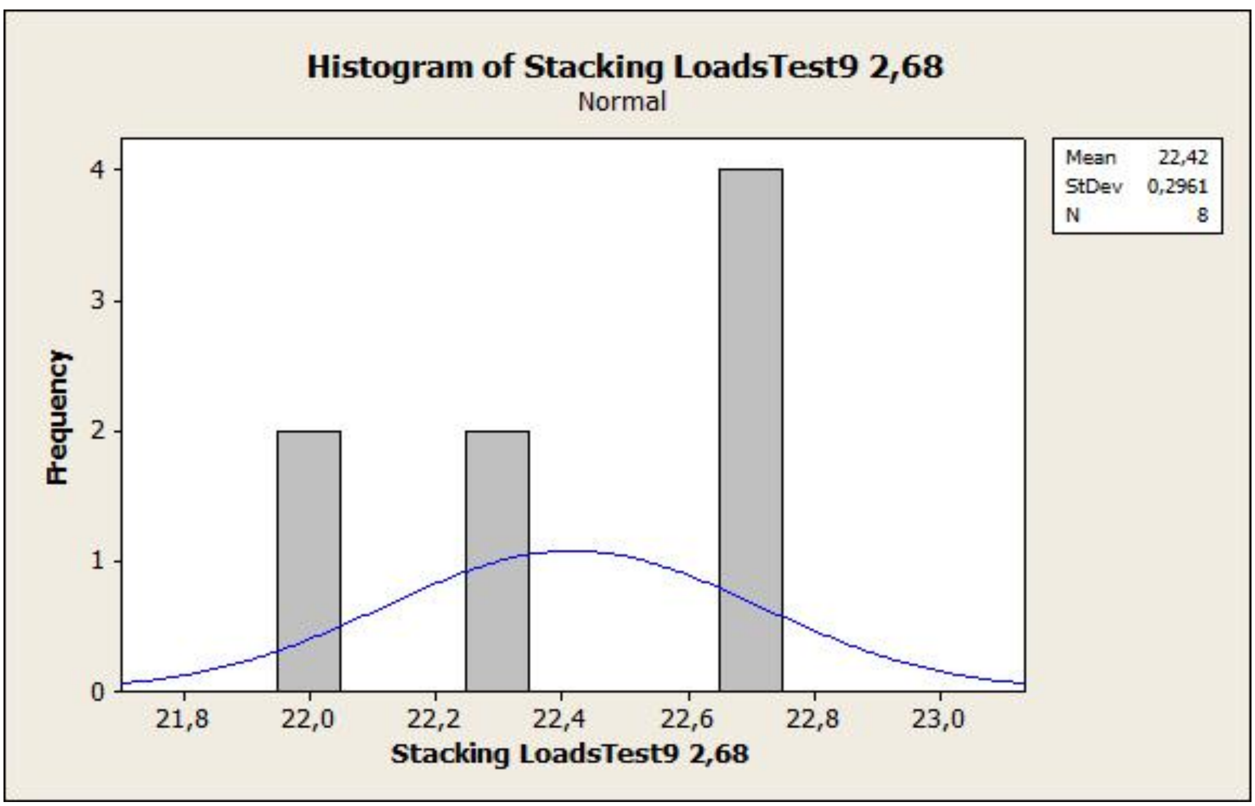


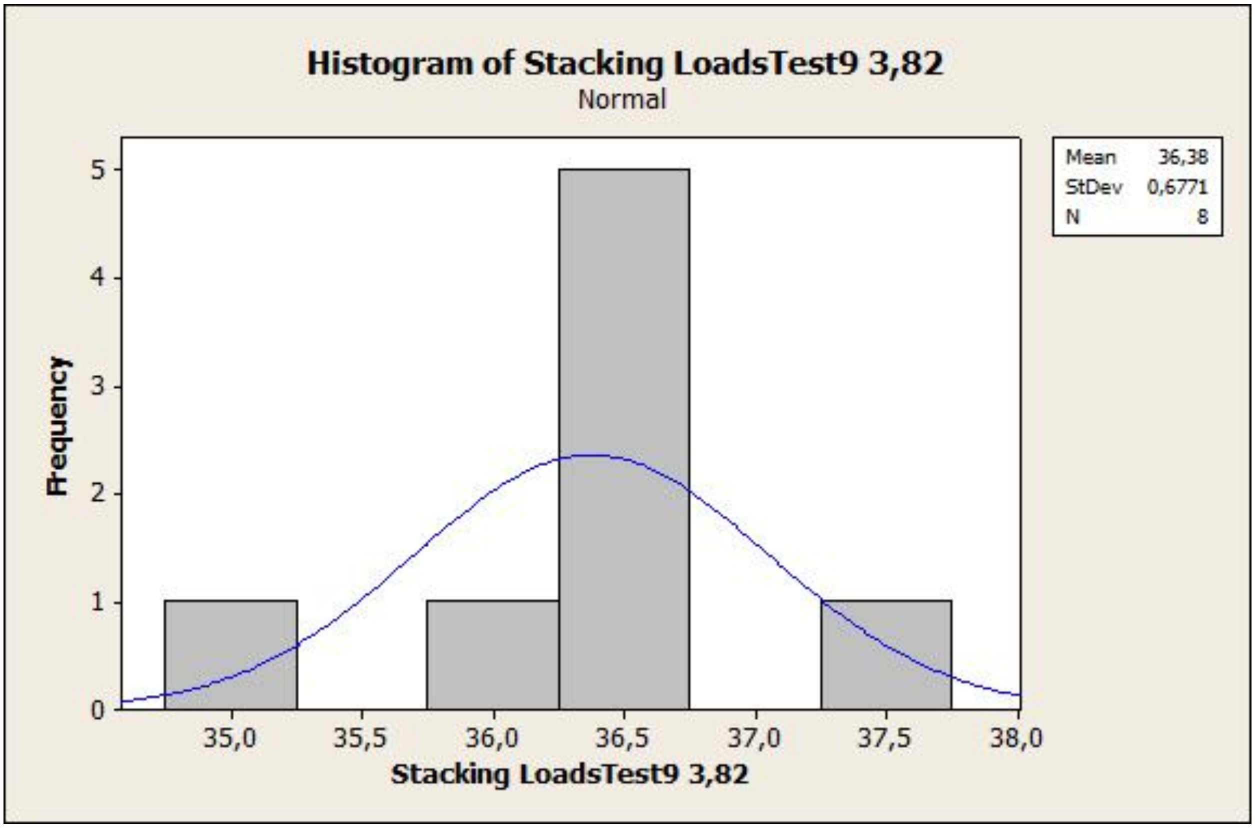



Histogram of Stacking LoadsTest7 3,82
Normal
Mean 39,97
StDev 1,047
N 9
Frequency
2,0
1,5
1,0
0,5
0,0
38
39
40
41
42
Stacking LoadsTest7 3,82

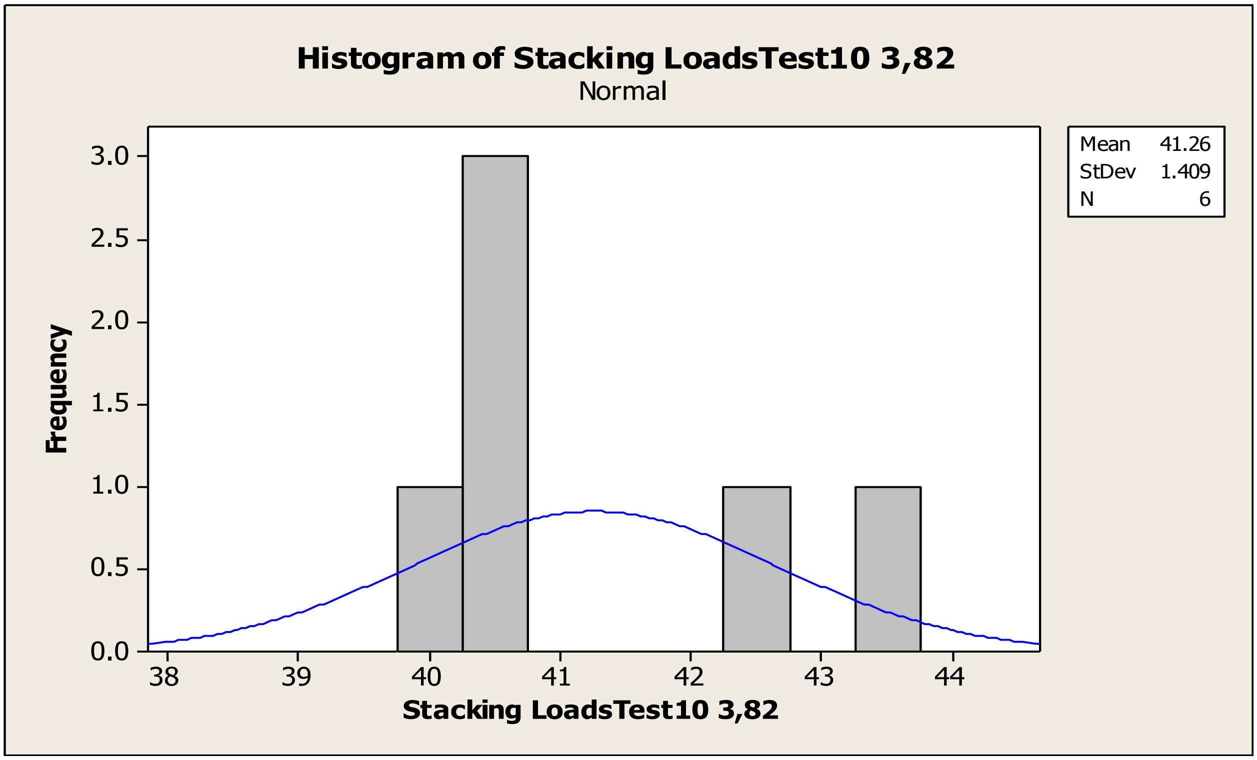
9.2.6. Condition 9

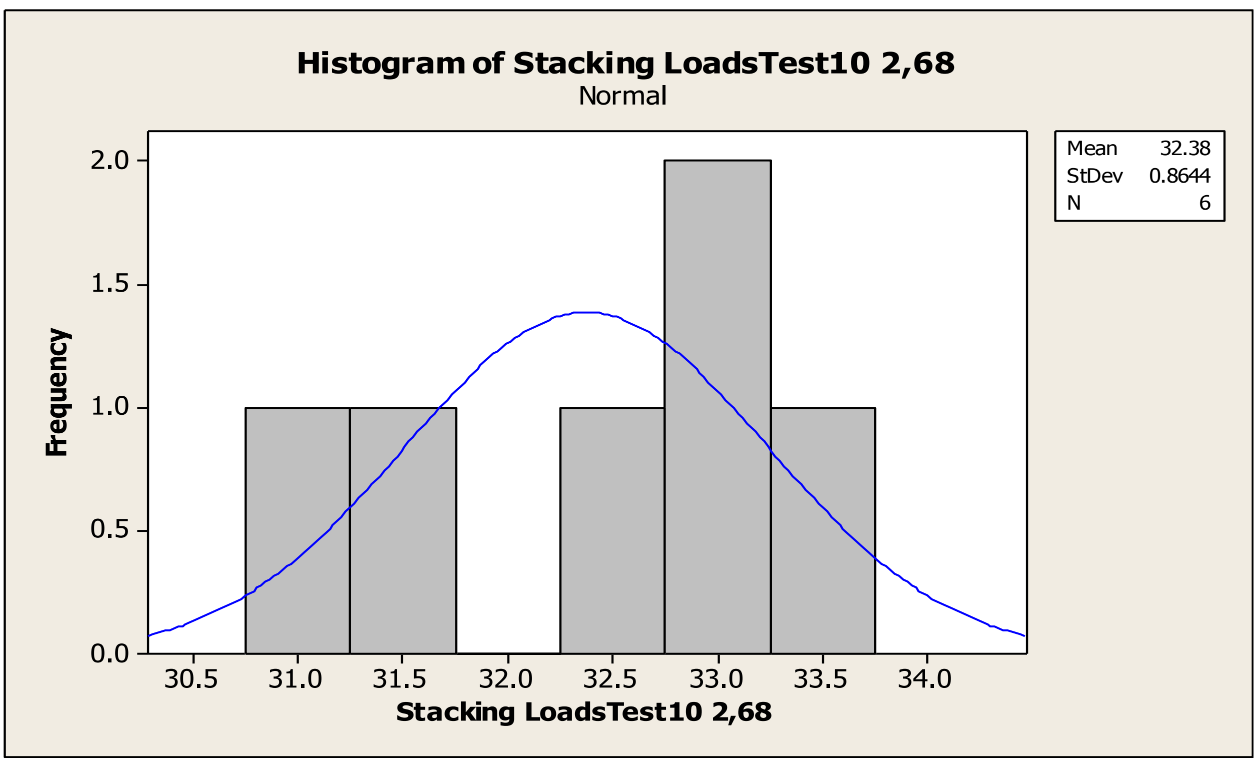


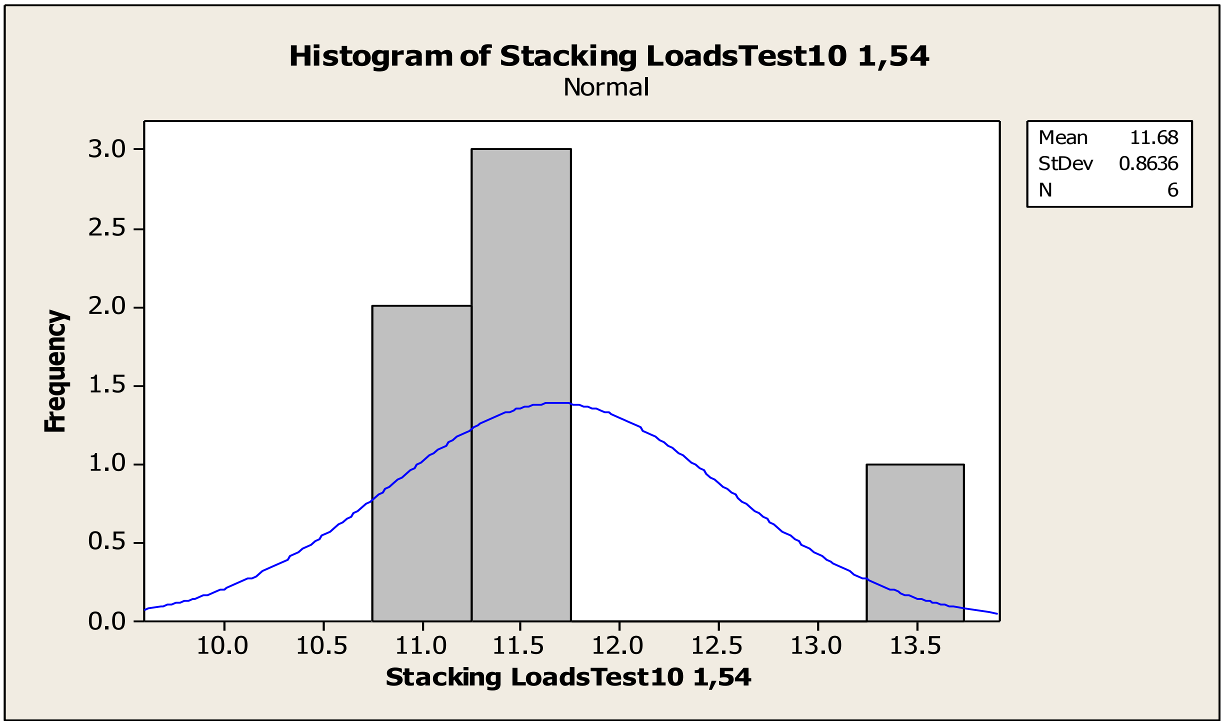



Histogram of Stacking LoadsTest9 3,82
Normal
Mean 36,38
StDev 0,6771
N 8
Frequency
0
1
2
3
4
5
35,0
35,5
36,0
36,5
37,0
37,5
38,0
Stacking LoadsTest9 3,82

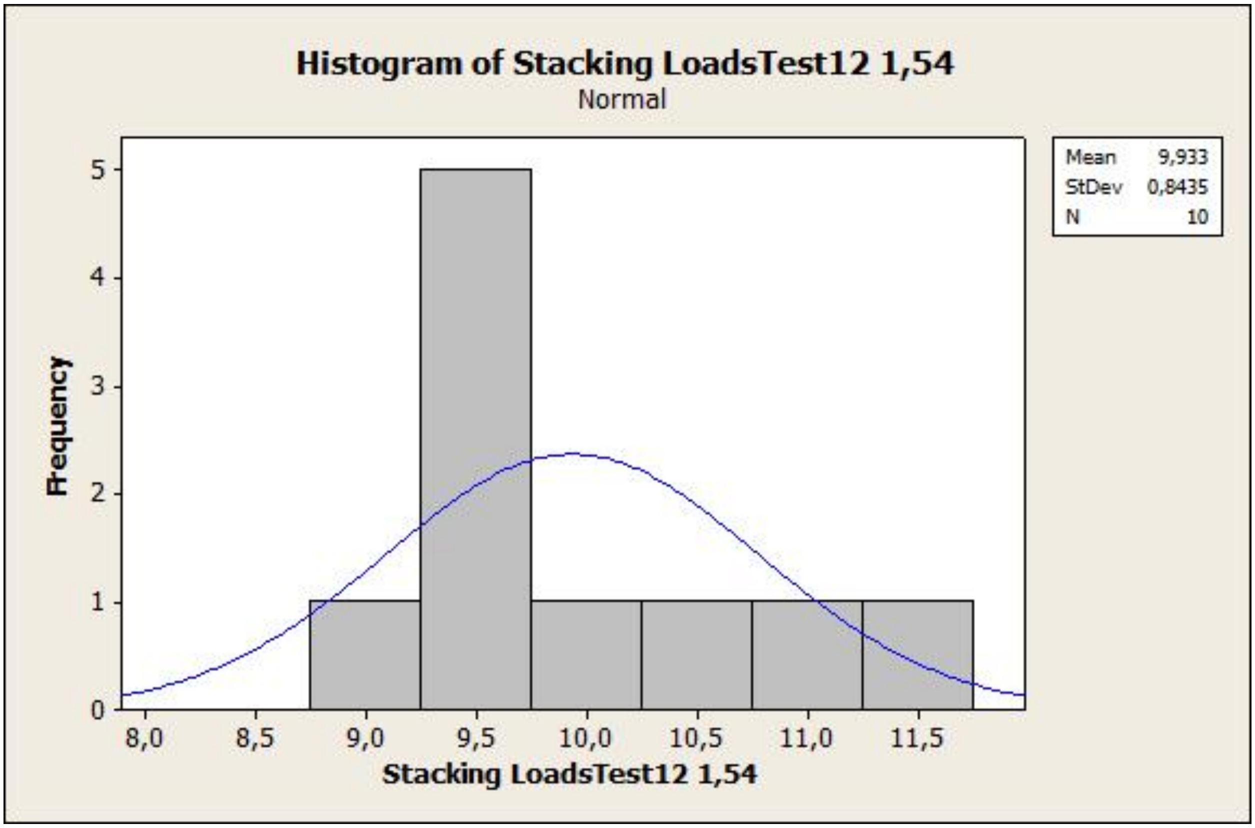
9.2.7. Condition 10

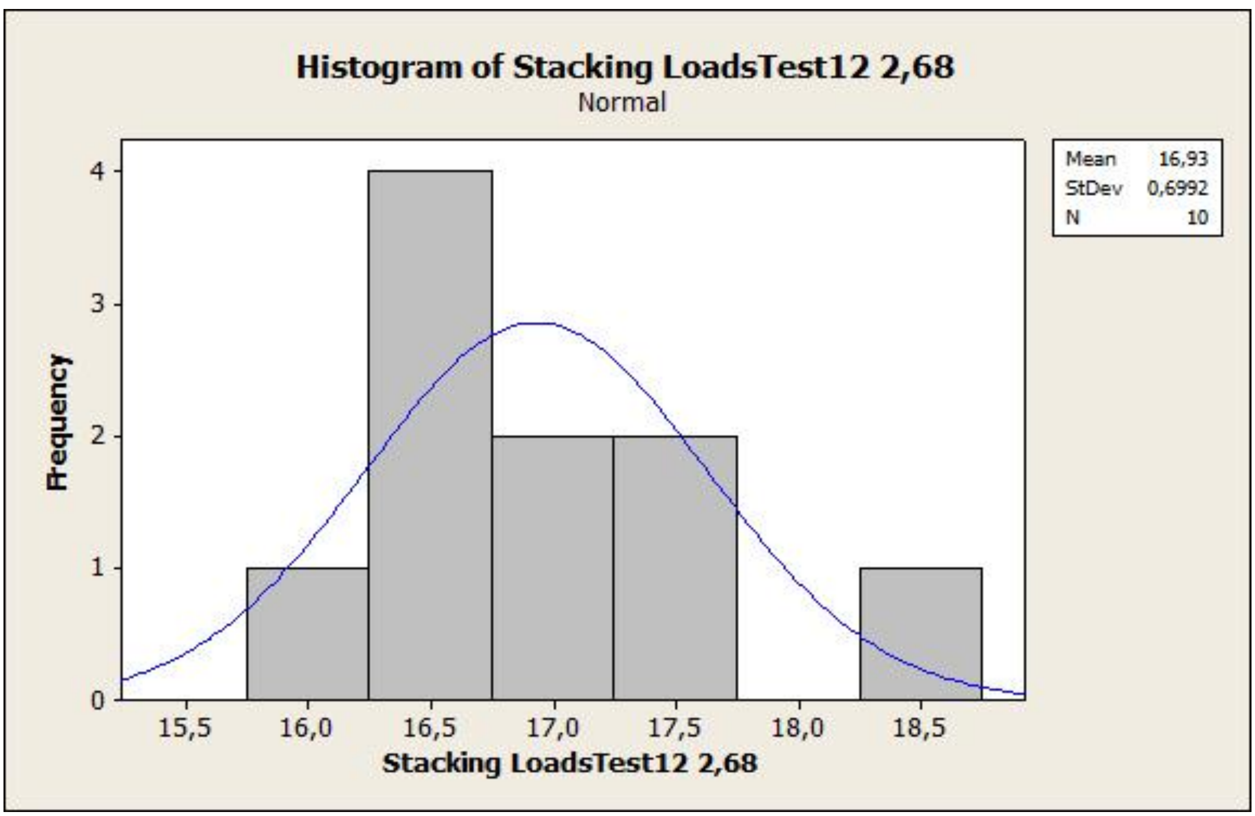


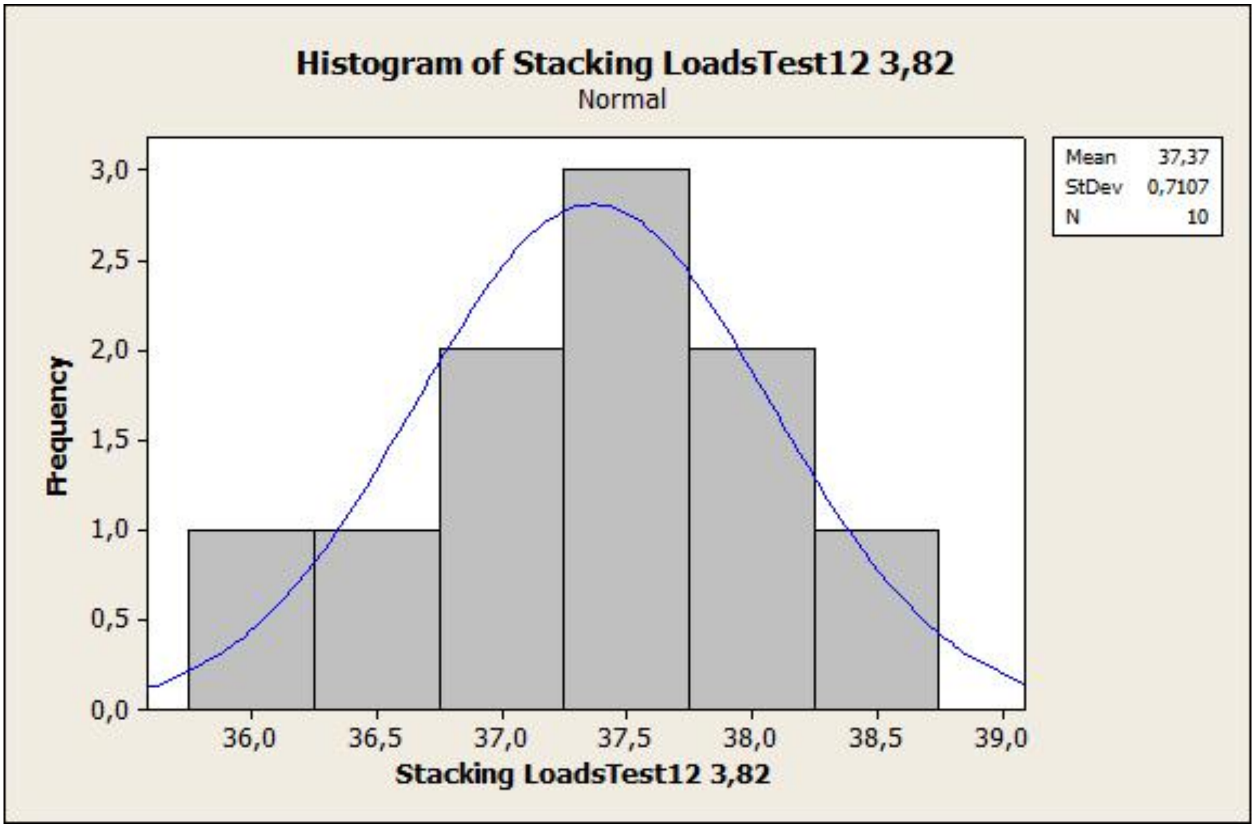



Histogram of Stacking LoadsTest10 1,54
Normal
Mean 11.68
StDev 0.8636
N 6
Frequency
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
Stacking LoadsTest10 1,54

9.2.8. Condition 12






Histogram of Stacking LoadsTest12 3,82
Normal
Mean 37,37
StDev 0,7107
N 10
Frequency
3,0
2,5
2,0
1,5
1,0
0,5
0,0
36,0
36,5
37,0
37,5
38,0
38,5
39,0
Stacking LoadsTest12 3,82

9.3. Math Cad

Determining a Stacking load ISO 16104 5.3.2.2

Where water is used as test contents, the stacking load to be superimposed on each packaging shall be calculated
from the following:
$M_1 = ((H/h) - 1)(C.d.n+m)$
where:
M_1 Is the stacking load in kilograms (kg) (see note);
H Is the relevant stack height in millimeters (mm) (minimum 3000 mm);
h Is the overall height of the packaging in millimeters (mm), allowing for any interstacking features (see
7.2.1);
C Is the volume of water in liters (l) required to occupy 98 % of the brimful capacity or, for combination
packagings, 98 % of the brimful capacity of one inner packaging (see 5.3.3.1)
d Is the relative density of the substance to be transported;
m Is the mass in kilograms (kg) of the empty packaging (including its closures) or, for combination
packagings, the mass of all the components of one package, including empty inner packagings (see
7.2.1);
n Is the one or a number of inner packagings (combination packaging only).

$H := 3000mm$

$h := 416mm$

$C := 24.25L$

$d_{water} := 1.\frac{kg}{L} \qquad d_{nitricacid} := 1.42\frac{kg}{L}$

$m := 1kg \qquad g := 9.807\frac{m}{s^2}$

$$M_1 := \left[\left(\frac{H}{h}\right) - 1\right](C \cdot d_{water} + m) \rightarrow \left(\frac{3000\,mm}{416\,mm} - 1\right) \cdot \left(24.25L \cdot 1. \cdot \frac{kg}{L} + kg\right) = 156.841kg$$

$M_1 = 156.841kg$

Minimum weight

$$M_1 \cdot g \qquad 156.841kg \cdot 9.807\frac{m}{s^2} = 1.538kN$$

Number of Jerricans in a 3m stack

$$\frac{H}{h} \rightarrow \frac{3000\,mm}{416\,mm} = 7.212$$

$$N := \begin{pmatrix} \frac{H}{h} \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} \rightarrow \begin{pmatrix} \frac{3000\,mm}{416\,mm} \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} = \begin{pmatrix} 7.212 \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix}$$

$$H_1 := N \cdot h \rightarrow \begin{pmatrix} 7.212 \\ 8 \\ 9 \\ 10 \\ 12 \end{pmatrix} \cdot 416\,mm = \begin{pmatrix} 3 \\ 3.328 \\ 3.744 \\ 4.16 \\ 4.992 \end{pmatrix} m$$

$$M_{water} := \left[\left(\frac{H_1}{h}\right) - 1\right]\left(C \cdot d_{water} + m\right) \cdot g \rightarrow \left(\frac{H_1}{416\,mm} - 1\right) \cdot \left(24.25L \cdot 1. \cdot \frac{kg}{L} + kg\right) \cdot 9.807 \frac{m}{s^2} = \begin{pmatrix} 1.538 \\ 1.733 \\ 1.981 \\ 2.229 \\ 2.724 \end{pmatrix} \cdot kN$$

$$M_{nitricacid} := \left[\left(\frac{H_1}{h}\right) - 1\right]\left(C \cdot d_{nitricacid} + m\right) \cdot g \rightarrow \left(\frac{H_1}{416\,mm} - 1\right) \cdot \left(24.25L \cdot 1.42 \frac{kg}{L} + kg\right) \cdot 9.807 \frac{m}{s^2} = \begin{pmatrix} 2.159 \\ 2.433 \\ 2.78 \\ 3.128 \\ 3.823 \end{pmatrix} \cdot kN$$

$$Load_{min} := M_{water_0} = 1.538\,kN \qquad Load_{max} := M_{nitricacid_4} = 3.823\,kN$$

$$Load_{med} := \frac{Load_{max} + Load_{min}}{2} \qquad \frac{3.823\,kN + 1.538\,kN}{2} = 2.68\,kN$$

Determining if the reactions are equal on the guided and unguided compression average deflections at the 3 loads for all unguided compression tests

$$x_{10} := \begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix} \qquad x_{12} := \begin{pmatrix} 9.93 \\ 16.93 \\ 37.37 \end{pmatrix} \qquad x_{7} := \begin{pmatrix} 19.34 \\ 26.29 \\ 39.97 \end{pmatrix} \qquad x_{9} := \begin{pmatrix} 16.13 \\ 22.42 \\ 36.38 \end{pmatrix}$$

Equation for 60mm deflection of centered jerricans

$$\text{Angle} = .0002x^3 - .0149x^2 + .1949x$$

$$\theta_{10} := .0002x_{10}^3 - .0149x_{10}^2 + .1949x_{10} \text{ explicit}, x_{10} \rightarrow .0002\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix}^3 - .0149\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix}^2 + .1949\begin{pmatrix} 11.68 \\ 32.38 \\ 41.180 \end{pmatrix} = \begin{pmatrix} 0.562 \\ -2.521 \\ -3.275 \end{pmatrix}$$

$$\theta_{12} := .0002x_{12}^3 - .0149x_{12}^2 + .1949x_{12} \text{ explicit}, x_{12} \rightarrow .0002\begin{pmatrix} 9.93 \\ 16.93 \\ 37.37 \end{pmatrix}^3 - .0149\begin{pmatrix} 9.93 \\ 16.93 \\ 37.37 \end{pmatrix}^2 + .1949\begin{pmatrix} 9.93 \\ 16.93 \\ 37.37 \end{pmatrix} = \begin{pmatrix} 0.662 \\ -5.421 \times 10^{-4} \\ -3.087 \end{pmatrix}$$

$$\theta_{7} := .0002x_{7}^3 - .0149x_{7}^2 + .1949x_{7} \text{ explicit}, x_{7} \rightarrow .0002\begin{pmatrix} 19.34 \\ 26.29 \\ 39.97 \end{pmatrix}^3 - .0149\begin{pmatrix} 19.34 \\ 26.29 \\ 39.97 \end{pmatrix}^2 + .1949\begin{pmatrix} 19.34 \\ 26.29 \\ 39.97 \end{pmatrix} = \begin{pmatrix} -0.357 \\ -1.54 \\ -3.243 \end{pmatrix}$$

$$\theta_{9} := .0002x_{9}^3 - .0149x_{9}^2 + .1949x_{9} \text{ explicit}, x_{9} \rightarrow .0002\begin{pmatrix} 16.13 \\ 22.42 \\ 36.38 \end{pmatrix}^3 - .0149\begin{pmatrix} 16.13 \\ 22.42 \\ 36.38 \end{pmatrix}^2 + .1949\begin{pmatrix} 16.13 \\ 22.42 \\ 36.38 \end{pmatrix} = \begin{pmatrix} 0.106 \\ -0.866 \\ -3 \end{pmatrix}$$

$$\frac{\theta_7 \cdot \pi}{180} = \begin{pmatrix} -0.357 \\ -1.54 \\ -3.243 \end{pmatrix} \cdot \text{deg} \qquad \frac{\theta_9 \cdot \pi}{180} = \begin{pmatrix} 0.106 \\ -0.866 \\ -3 \end{pmatrix} \cdot \text{deg} \qquad \frac{\theta_{10} \cdot \pi}{180} = \begin{pmatrix} 0.562 \\ -2.521 \\ -3.275 \end{pmatrix} \cdot \text{deg}$$

$$\frac{\theta_{12} \cdot \pi}{180} = \begin{pmatrix} 0.662 \\ -5.421 \times 10^{-4} \\ -3.087 \end{pmatrix} \cdot \text{deg}$$

Resultant loads $\quad \text{Resultant} = \sqrt{\sin(\theta_x)\,\text{Load}_{\text{Instron}}{}^2 + \text{Load}_{\text{Instron}}{}^2}$

$$\sqrt{\left(\sin\left(\theta 7_0\,\text{deg}\right)\cdot\text{Load}_{\text{min}}\right)^2 + \text{Load}_{\text{min}}{}^2} = 1.538\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 9_0\,\text{deg}\right)\cdot\text{Load}_{\text{min}}\right)^2 + \text{Load}_{\text{min}}{}^2} = 1.538\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 7_1\,\text{deg}\right)\cdot\text{Load}_{\text{med}}\right)^2 + \text{Load}_{\text{med}}{}^2} = 2.681\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 9_1\,\text{deg}\right)\cdot\text{Load}_{\text{med}}\right)^2 + \text{Load}_{\text{med}}{}^2} = 2.681\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 7_2\,\text{deg}\right)\cdot\text{Load}_{\text{max}}\right)^2 + \text{Load}_{\text{max}}{}^2} = 3.829\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 9_2\,\text{deg}\right)\cdot\text{Load}_{\text{max}}\right)^2 + \text{Load}_{\text{max}}{}^2} = 3.828\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 10_0\,\text{deg}\right)\cdot\text{Load}_{\text{min}}\right)^2 + \text{Load}_{\text{min}}{}^2} = 1.538\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 12_0\,\text{deg}\right)\cdot\text{Load}_{\text{min}}\right)^2 + \text{Load}_{\text{min}}{}^2} = 1.538\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 10_1\,\text{deg}\right)\cdot\text{Load}_{\text{med}}\right)^2 + \text{Load}_{\text{med}}{}^2} = 2.683\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 12_1\,\text{deg}\right)\cdot\text{Load}_{\text{med}}\right)^2 + \text{Load}_{\text{med}}{}^2} = 2.68\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 10_2\,\text{deg}\right)\cdot\text{Load}_{\text{max}}\right)^2 + \text{Load}_{\text{max}}{}^2} = 3.829\text{kN}$$

$$\sqrt{\left(\sin\left(\theta 12_2\,\text{deg}\right)\cdot\text{Load}_{\text{max}}\right)^2 + \text{Load}_{\text{max}}{}^2} = 3.828\text{kN}$$