Processing And Analysis of Experimental Data for the Impact Residual Strain ($\varepsilon_{residual}$) Of the Steel Quality Using Design Expert Software

Malush Mjaku[1] & Ahmet Shala [2]
[1] University of Prizren, Faculty of Computer Science, Prizren, Kosovo
[2] University of Prishtina / Faculty of Mechanical Engineering, Prishtina, Kosovo

***Abstract**: Object of this study is the steel quality J55 API 5CT and the process of pipe forming Ø139.7×7.72[mm], Ø244.5×8.94[mm], and Ø323.9×7.10[mm], with longitudinal seam pipes-ERW Aim of this paper is to study the impact of plastic deformation degree in the cold of residual strain in the cross section area of steel quality pipes J55 API 5CT [1]. For the realization of this study we have used the planning method of the experiment with one-factor. We have built the mathematical model for the experiment with one index (residual strain) and with one factor (deformation degree in the cold) and with three deformation levels. The results obtained in an experimental method are shown in the table and are processed in an analytical way while implementing the one factored experiments [2].*

***Keywords**: One-factor experiments, pipe, residual strain, Design Expert Software.*

1. INTRODUCTION

During the technologic production process of the longitudinal seam pipes significant factor with influence is the plastic deformation in the cold which is realized according to distorting forces on the curvature during the process of forming and calibration of pipes. It is expected that the impact to be much higher the smaller the pipe diameter is. To discover and evaluate this impact in , residual strain we made measures for three pipe diameters: Ø139.7x7.72[mm], Ø244.5x8.94[mm], and pipe Ø323.9x7.10[mm]. These three pipe profiles express three levels (1, 2 and 3) of the quality factor “deformation degree”. For each level are performed four tests3. The slitting rings are taken from the profiles of these pipes and tests are performed while applying the criteria of the chance. The measured indicator is, residual strain during forming and calibration in cross cutting of the pipes, marked with y. Given results (tab. 1) of the deformation stresses are calculated according to the equation 1 [1].

$$\sigma = E \cdot t\left(\frac{1}{D_0} - \frac{1}{D_1}\right) = \sigma = E \cdot t\left(\frac{1}{D_0} - \frac{1}{D_1}\right) \quad (1)$$

$$\varepsilon = \frac{\sigma}{E} = \frac{82}{2 \cdot 10^5} = |0.00041 \cdot 10^6 = 410[\mu\varepsilon]$$

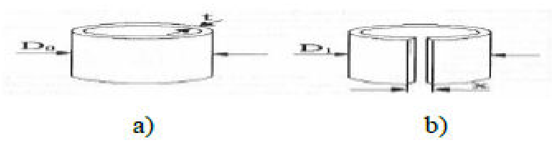


Figure 1: Schematic of the residual stress distribution in rings manufactured from tube: a) before and b) after slitting. E - modulus elasticity; t - thickness; D_0 - initial diameter; D_1 diameter after slitting; x - net opening displacement [4].

Table 1: Results of residual strain

Reiterations/Levels	R=162[mm]	R=122[mm]	R=70[mm]
1	410.00	467.53	827.00
2	386.65	472.50	785.00
3	328.61	423.00	704.43
4	323.00	661.88	692.00
Sum Y_{i+}	1448.26	2024.91	3008.43 y_{++}= 6481.60
Average values $\overline{Y}_{i+}$	362.06 $\overline{Y}_{1+}$	506.22 $\overline{Y}_{2+}$	752 $\overline{Y}_{3+}$

2. MATHEMATICAL MODEL AND STATISTICAL ANALYSIS

2.1 Mathematical Model

Mathematical model which is predicted to reflect such a study is composed from a system by *n* equations forms [5].

$$y_{ij} = m + a_1 + \varepsilon_{ij}$$
$$y_{1j} = 540 + (-177.94) + \varepsilon_{1j}$$
$$y_{2j} = 540 + (-33.78) + \varepsilon_{2j} \quad (2)$$
$$y_{3j} = 540 + 212 + \varepsilon_{3j}$$

The formulas for calculation of round constant in which are based all observing results of index/indicator y(m) and effects (a_i) are:

$$\overline{m} = \frac{1}{n} \cdot y_{++} = \frac{1}{12} \cdot 6481.60 = 540 \quad (3)$$

$$\overline{a}_i = \frac{1}{p} y_{i+} - \overline{m} \quad (4)$$

Based on values from table 1 and formulas (2) we will have:

$$\left.\begin{array}{l} \overline{m} = \overline{y}_{++} \\ \overline{a}_i = \overline{y}_{i+} - \overline{y}_{++} \quad i=1,2\ldots,\mu \end{array}\right\} \quad (5)$$

$$\overline{a}_1 = \overline{y}_{1+} - \overline{y}_{++} = 362.06 - 540 = -177.94$$
$$\overline{a}_2 = \overline{y}_{2+} - \overline{y}_{++} = 506.22 - 540 = -33.78$$
$$\overline{a}_3 = \overline{y}_{3+} - \overline{y}_{++} = 752 - 540 = 212$$

2.2. Statistical Analysis

Variance Analysis: Total sum of the squares of differences (deviations) of the measured values from the average is composed by two components [2]:

$$S = S_g + S_p = 51912 + 311164 = 363076$$

Value of summary of error squares S_g is:

$$S_g = \sum_{i=1}^{\mu}\sum_{j=1}^{p}(y_{ij} - \bar{y}_{i+})^2 = \sum_{i=1}^{\mu}\left[\sum_{j=1}^{p} y_{ij}^2 - \frac{1}{p}\left(\sum_{i=1}^{p} y_{ij}\right)^2\right] \quad (6)$$

$$S_g = \sum_{i=1}^{\mu}\sum_{j=1}^{p} y_{ij}^2 - \frac{1}{p}\sum_{i=1}^{p} y_{i+}^2 = \sum_{i=1}^{3}\sum_{j=1}^{4} y_{3,4}^2 - \frac{1}{4}\sum_{i=1}^{3} y_{3+}^2 = 3864004 - \frac{1}{4}\cdot 15248368 = 51912$$

$$\sum_{i=1}^{3}\sum_{j=1}^{4} y_{3,4}^2 = 410^2 + 467.53^2 + 827^2 + \ldots + 704.63^2 + 692^2 = 3864004$$

$$\sum_{i=1}^{3} y_{1+}^2 = 1448.26^2 + 2024.91^2 + 3008.43^2 = 15248368$$

$$y_{++}^2 = 6481.60^2 = 42011138.56$$

In similar method we will have also the value of deviation of experimental mistake.

$$S_p = \frac{1}{p}\sum_{i=1}^{u} y_{i+}^2 - \frac{1}{\mu \times p} y_{++}^2 = \frac{1}{4}\sum_{i=1}^{3} y_{i+}^2 - \frac{1}{3\times 4} y_{++}^2 = \frac{1}{4}\cdot 15248368 - \frac{1}{12}\cdot 42011138 = 311164$$

2.3 Control of Hypothesis, upon equality of the effects

For this is required control of hypothesis based on the equality of the effects a_i. According to the equation (2), hypothesis of equation of the effects H_0, will take the form[6]:

$$H_0: a_1 = a_1 = \ldots = a_\mu = 0 \quad (7)$$

Alternative hypothesis is H_1:

$$a_i \neq 0 \quad (8)$$

Table 2: Summary table of variance analysis

Reason of change	**Sum of squares**	**No. of DOF**	**Average square of deviations**
Processing	$S_p = 311164$	$\mu - 1 = 2$	$s^2_p = 155582$
Reasons of the case	$S_g = 51912$	$n - \mu = 9$	$s_g^2 = 5768$
Sum of deviations	$S = 363076$	$n - 1 = 11$	

Value of calculated Fisher's criteria is:

$$F_R = \frac{s_p^2}{s_g^2} = \frac{155582}{5768} = 26.97 \quad (9)$$

For level of importance $\alpha = 0.05$ limit value of Fisher's criteria:

$$F_R > F_{\alpha;\mu-1,n-\mu}$$

$$F_t(\alpha);2;9 = (0.05);2;9 = 4.26$$

$$F_R = 26.97 > F_t = 4.26$$

Then, with the level of importance $\alpha = 0.05$ hypothesis H_0 is rejected and effects a_i (i =1,2,3) are accepted.

2.4. Comparison of the effects

Comparison of the effects according to minimal valid difference: To emphasize which levels are with important changes, first is required to calculate minimal valid difference Δ_{ik} (α) for the level of importance α = 0.05

$$\Delta_{ik}(\alpha)=\sqrt{s_g^2\left(\frac{1}{p_i}+\frac{1}{p_k}\right)(\mu-1)\cdot F(\alpha;\mu-1,n-\mu)} \quad (10)$$

$$\Delta_{ik}(0.05)=\sqrt{5768\left(\frac{1}{4}+\frac{1}{3}\right)\cdot 2\cdot 4.26}=169.31$$

Based on the criteria (11) levels of effects "*i"* and *"k"* factor, so it compares (a_i) and (a_k):

$$\left|\bar{a}_i-\bar{a}_k\right|>\Delta_{ik}(\alpha) \quad (11)$$

$$|752 - 506.22| = 245.78;\ 245{,}78 > 169.31$$

$$|\ \bar{y}_{i+} - \bar{y}_{k+}| > \Delta_{ik}(\alpha) \quad (12)$$

$$|212- (-33.78)| = 245.78;\ 245.78>169.31$$

From application of this criteria result that between levels 3 and 1 it has important impact:

$$|\ \bar{y}_{3+} - \bar{y}_{1+}| = |752\ 362| = 390 > 169.31$$

Between levels 3 and 2 it has important:

$$|\ \bar{y}_{3+} - \bar{y}_{2+}| = |752\ 506.22| = 245.78 > 169.31$$

Between levels 3 and 2 it hasn't important impact:

$$|\ \bar{y}_{3+} - \bar{y}_{2+}| = |506.22\ 362| = 144.22 < 169.31$$

Comparison of the effects according to collective criteria of deviations: In this way "first type of mistake" to revoke a true hypothesis would be: 1- 0.857 = 0.142 (and no more 0.05). To avoid this increment of mistake we should use other criteria, Duncan's collective criteria of deviations, which will be described below. In case when number of experiments p in every level is same, standard mistake is calculated[2]:

$$C_b^a\frac{b!}{a!(b-a)!}=C_3^2=\frac{3\cdot 2\cdot 1}{2\cdot 1}=3 \quad (13)$$

$$(0.95)^3 = 0.857$$

$$1- 10.857 = 0.142$$

$$S_{\bar{y}_{i+}}=\sqrt{\frac{1}{p}\cdot s_g^2}=\sqrt{\frac{1}{4}5768}=37.97$$

By statistical tables, for $\alpha = 0.05$ and number of degrees of freedom $f = n - \mu = 12 - 3 = 9$, are with row for q = 2,3 valid deviation: $r_{0.05(2;9)} = 3.08$ and $r_{0.05(3;9)} = 3.23$

With valid deviations r/α and standard mistakes of levels, calculation of minimal valid deviations according to the formula:

$$R_q = r_\alpha(q,f)\ .S_{\bar{y}_{i+}},\quad q=2,3,\ldots,\mu \quad (14)$$

$f = n\text{-}\mu = 12\text{-}3 = 9$

$r_{0.05(2;9)} = 3.08;\ r_{0.05(3;9)} = 3.23$

$R_2 = 3.08\ 37.97 = 116.94;\ R_3 = 3.23\ 37.97 = 122.64$

1	2	3
y_{1+}	y_{2+}	y_{3+}
362	506.22	752

$\bar{y}_{3+} - \bar{y}_{1+} = 752 - 362 = 390 > 122.64 = R_3;\ q=3-1+1=3$

$\bar{y}_{3+} - \bar{y}_{2+} = 752 - 506.22 = 245.78 > 37.97 = R_2;\ q=3-2+1=2$

$\bar{y}_{2+} - \bar{y}_{1+} = 506.22 - 362 = 144.22 > 37.97 = R_2;\ q=2-1+1=2$

PROCESSING DATA WITH DESIGN-EXPERT SOFTWARE

Response 1 Residual Strain

ANOVA for selected factorial model

Analysis of variance table [Classical sum squares – Type II]

Source	Sum of Squares	df	Mean Square	F Value	p – value Prob > F
Model	3.116E+005	2	1.558E+005	27.08	0.0002 significant
A- Def. Degree	3.116E+005	2	1.558E+005	27.08	0.0002
Pure Error	51765.50	9	5751.72		
Cor Total	3.633E+005	11			

The Model F-value of 27.08 implies the model is significant. There is onlya 0.02% chance that a "Model FValue" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A are significant model terms.

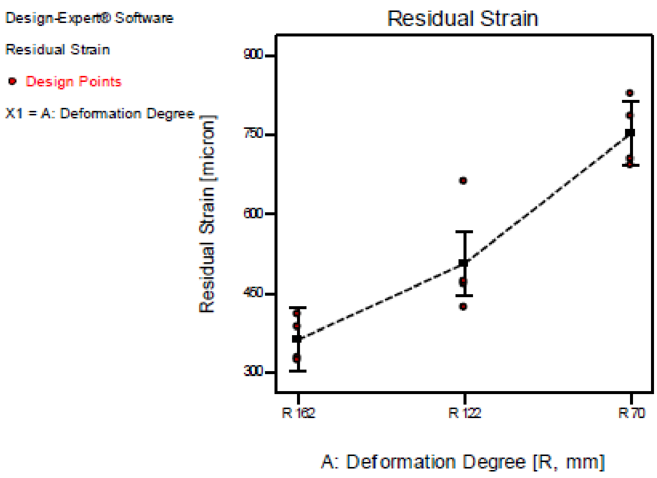
Std. Dev.	75.84	R-Squared	0.8575
Mean	539.83	Adj R-Squared	0.8259
C.V. %	14.05	Pred R-Squared	0.7467
PRESS	92027.56	Adeq Precision	10.291

The "Pred R-Squared" of 0.7467 is in reasonable agreement with the "Adj R-Squared" of 0.8259. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 10.291 indicates an adequate signal. This model can be used to navigate the design space. **Treatment Means**

Treatment	Mean Difference	df	Standard Error	t for H0 Coeff=0	Prob>|t|
1 vs 2	-144.00	1	53.63	-2.69	0.0250
1 vs 3	-390.25	1	53.63	-7.28	<0.0001
2 vs 3	-246.25	1	53.63	-4.59	0.0013

Values of "Prob > |t|" less than 0.0500 indicate the difference in the two treatment means is significant.

Design-Expert® Software Residual Strain



CONCLUSION

In three applied methods (criteria) for results analysis, with degree of decreasing the mistake of the first type, from 0.142, in 0.05 and in p = 0.0001, are confirming the forming of pipes, the deformation degree throughout the bending of sheet and calibration in the cold influences in the increase of residual stresses. The influence of the impact is much higher the smaller the pipe diameter is.

REFERENCES

[1] Standard: API Specification 5CT, Washington 2000.

[2] V. Kedhi, Methods of planning and analysis of experiments, Polytechnic Faculty, Tirana 1984.

[3] Standard: ASTM-A370, Washington 2000.

[4] http://www.asminternational.org/pdf/spotlights/6700_89-98_web.pdf

[5] I. Pantelić: Introduction on theory of engineering experiments, Professional Book, Radnicki Universitet, Novi Sad, ex. Yougoslavia, 1976.

[6] Douglas C. Mongomery: *Controllo statistico di qualità, Parte III:* (Statistical controll of quality), McGraw-Hill, 2000.

[7] Software: Design Expert 7