Impact of Various Factors Affecting Uncertainty Measurement in Material Testing

Dr. Nitin K. Mandavgade

Associate Professor, Department of Mechanical Engineering,
Nagpur Institute of Technology, Nagpur, Maharashtra, 440016, India.

Abstract- The material testing is very importance from quality perspective**.** The globalization of Indian economy and the liberalization policies initiated by the Government in reducing trade barriers and providing greater thrust to exports makes it imperative for Accredited Laboratories to be at international level of competence. Measurement Uncertainty – This term refers to a measurement plus or minus a particular range that best represents the true value. This allows for the fact that actual reading may not be entirely accurate, and so the range accounts for that possibility. A measurement without a degree of uncertainty is simply a "reading": even national standards laboratories such as the NPL, NRCC and NIST make use of measurement uncertainty over standard readings as these values will include all variables. Being aware of these variables and the range of numbers that the measurement encompasses provides certain benefits. A realistic uncertainty reading also lends greater credibility to the measurement information being produced. In an effort to meet National, International, and Commercial Accreditation requirements, users of Materials Testing Machines must establish adequate methods of determining calibration and test measurement uncertainties. Determining measurement uncertainty for testing machines and test data can be a very complex process. Many factors affect the uncertainty of test data produced by testing machines.

Keywords- Uncertainty of Measurement; Tensile testing ; % Elongation; Brinell Hardness testing; Rockwell Hardness Test; Mathematical Modeling.

1. Introduction –

NABL Accreditation- Laboratory Accreditation provides formal recognition of competent laboratories, thus providing a ready means for customers to find reliable testing and calibration services in order to meet their demands. Laboratory Accreditation enhances customer confidence in accepting testing / calibration reports issued by accredited laboratories .The globalization of Indian economy and the liberalization policies initiated by the Government in reducing trade barriers and providing greater thrust to exports makes it imperative for Accredited Laboratories to be at international level of competence [1,10,11].

2. Evaluation of Uncertainty of Measurement-

First of all: a laboratory that has a good quality management system should have little effort to state the uncertainty of a result. The principles for correct application of measurement uncertainties are given in the [1].

In case of universal tensile testing machine, we have performed number of test for each parameter. Two types of uncertainties are associated with each measuring parameters [8, Eurolab 2002].

To calculate uncertainty following steps are to be followed [7, 8]-

Step 1) Specify measurand, express mathematically the equation relating measurand and input quantities. Identify all uncertainty sources.
Step 2) Determine the input quantities.
Step 3) Quantify the standard uncertainties of all single components.
Step 4) Identify the covariance (of correlated input quantities).
Step 5) Calculate the result of the measurement from the input quantities.
Step 6) Calculate the combined uncertainty.
Step 7) Calculate the expanded uncertainty.
Step 8) Give the result together with the uncertainty as estimated.

2.1 Evaluation of Uncertainty of Measurement in Tensile stress in UTM.

Instrument:-UTM
Make - FIE model UTN – 60
Sample - 5 no test pieces

Table No 2.1 observation table of tensile test

Sample No.	Diameter (Average of 2 reading 90^0 apart) mm	Stress area (mm2)	Breaking load N	UTS MPa	Average MPa
1	16.02	201.56	182500	905.44	
2	16.02	201.56	182000	902.96	
3	16.02	201.56	182000	902.96	903.46
4	16.02	201.56	182000	902.96	
5	16.02	201.56	182000	902.96	

2.1.1 Combine uncertainty

$$\mathbf{U_c = \sqrt{U_{RA}^2 + U_{MB}^2 + U_{ZB}^2 + U_{SB}^2 + U_{TMB}^2}} \qquad \text{-------------------------(eq.7)}$$

Where,
1. Uncertainty due to repeatability - U_{RA}
2. Uncertainty due to micrometer - U_{MB}
3. Uncertainty due to zeroing - U_{ZB}
4 Uncertainty due to testing speed - U_{SB}
5. Uncertainty due to testing machine - U_{TMB}
6. Combine Uncertainty - U_C

Std deviation =1.109
No. of observations n = 5
Therefore, Std. uncertainty (U_{RA})

$$\frac{Sd}{\sqrt{n}} = \frac{1.109}{\sqrt{5}} = \pm 0.496 MPa$$

Degree of Freedom = n – 1 = 4

1. Uncertainty Due to micrometer - U_{MB}

Micrometer Uncertainty = $\pm$ 5.96 micron = $\pm$ 0.00596 mm

Considering uncertainty for maximum diameter (16.02596 mm, Area 201.7149 mm^2) and minimum diameter (1599404 mm, area 200.9122 mm^2) of test piece.

Max. UTS = Load maximum/ Area maximum

= 182500/ 201.7199 = 904.7423 MPa

Min. UTS = Load minimum/ Area minimum

= 182000/200.912 = 905.8683 MPa.

Deviation = Max. UTS – Min. UTS

= -1.126 MPa

UMB = deviation/$\sqrt{3}$ = -1.126 MPa / $\sqrt{3}$ = -0.6501 MPa

Considering Rectangular probabilities

DOF = ∞

2. U_{ZB}-Uncertainty Due to Zeroing -

Tensile test carried out in the scale 0 – 300 kN and least count is 500 N.

Then maximum Load will be = 182500 N + 500 N = 183000N

Minimum Load will be = 182000 N - 500 N = 181500N

Max. UTS = Load maximum/ Area maximum

= 183000/ 201.56 = 907.9182 MPa

Min. UTS = Load minimum/ Area minimum

= 181500/201.06 = 902.7156 MPa.

Deviation = Max. UTS – Min. UTS

= 5.2025MPa

U_{ZB}= deviation/ $\sqrt{3}$ = 5.2025MPa /$\sqrt{3}$ = 3.0031 MPa

Considering Rectangular probabilities

DOF = ∞

3. U_{SB} -Uncertainty Due to Testing Speed -

The error due to speed of testing is evaluated from experience found to be ± 0.2%

Then maximum Load will be = 182500 N + 365 N = 182865N

Minimum Load will be = 182000 N - 365 N = 181635N

Max. UTS = Load maximum/ Area maximum

= 183865/ 201.56 = 907.2485 MPa

Min. UTS = Load minimum/ Area minimum

= 181635/201.06 = 903.3920 MPa.

Deviation = Max. UTS – Min. UTS

= 3.8565MPa

U_{SB} = deviation/$\sqrt{3}$ = 3.8565MPa /$\sqrt{3}$ = 2.2265 MPa

Considering Rectangular probabilities ,DOF = ∞

4. U_{TMB} -Uncertainty Due to Testing Machine -

As per calibration certificate, machine error is + 1%

With breaking load of 182500 N and average UTS of 903.46 MPa, the uncertainty in indication is± 9.034 MPa.

$\mathbf{U_{TMB}}$ = ± 9.034 MPa

Considering normal distribution,DOF = ∞

Combined standard uncertainty is given by

$$\mathbf{U_c = \sqrt{U_{RA}^2 + U_{MB}^2 + U_{ZB}^2 + U_{SB}^2 + U_{TMB}^2}}$$

Uc = + 9.810 MPa

Effective DOF,

$$V_{eff} = \frac{U_C^4}{\frac{U_{RA}^4}{4} + \frac{U_{MB}^4}{\infty} + \frac{U_{ZB}^4}{\infty} + \frac{U_{TMB}^4}{\infty} + \frac{U_{SB}^4}{\infty}}$$

V_{eff} = 115268 ≈ ∞
Then coverage factor (k) for $V_{eff} = \infty$
At level of confidence of approximately 95 %,K= 1.96
Therefore Expanded uncertainty
U = Uc × k
U = 9.810 ×1.96 = ± 19.2276

2.1.2 Reporting of result
With coverage factor k=1.96 and of level of confidence 95 %, with $V_{eff} = \infty$, the ultimate tensile strength is reported as 903.46± 19.2276 MPa (2.128 %) .

Table No 2.2 Uncertainty Budget for Tensile Testing:-

sources	Estimated value	Distribution / Divisor	Sensitivity coeff.	DOF	Std uncertainty
Repeatability	0.469 MPa	Normal, 1	1	4	0.496
Micrometer	-1.126 MPa	Rectangular ,$\sqrt{3}$	1	∞	0.6501
zeroing	5.2025 MPa	Rectangular ,$\sqrt{3}$	1	∞	3.0037
Testing speed	3.8565MPa	Rectangular ,$\sqrt{3}$	1	∞	2.2265
Machine	± 9.034 MPa	Normal, 1	1	∞	9.034
Expanded Uncertainty		k=1.96			19.2276

2.2 ***Evaluation of Uncertainty of Measurement in % Elongation in UTM.***

Name of instrument: Universal tensile testing machine
Model: ZD – 100
OJ NO : 136
Calibrated on: 26.08.2009
Sample: 5 numbers tensile test piece

Table No 2.3 observation table of % Elongation

Sample No.	Diameter (average of 2 readings 90 apart) mm	Stress Area (mm^2)	% Elongation	Average
1	10.00	78.54	12.06	
2	10.00	78.54	11.86	
3	10.00	78.54	12.02	12.00
4	10.00	78.54	12.10	
5	10.00	78.54	12.00	

2.2.1 Expanded Uncertainty

Standard Uncertainty (U_{RA}) = Std. Deviation / $\sqrt{n}$
= 0.09/ $\sqrt{n}$
= 0.040
The overall Uncertainty of % Elongation

(Uc) $= \sqrt{U_{RA}{}^2 + U_{MB}{}^2 + U_{SB}{}^2}$ where, Uc = Combined Uncertainty

U_{RA} = Uncertainty due to Repeatability.

U_{MB} = Uncertainty due to Vernier Caliper.

U_{SB} = Uncertainty due to Testing Speed.

Uncertainty of Vernier Caliper is 0.015mm at K=2
U_{MB} = 0.015 /2
= 0.0075

2. Uncertainty due to Testing Speed. U_{SB}
The error due to speed of testing is evaluated from experience, found to be 0.2%
Then, Maximum length will be = 112 + 0.224
=112.224
Minimum length will be = 112 - 0.224 = 111.776
Maximum % elongation = (Maximum length - initial length / initial length) X 100
= 12.224
Minimum % elongation = = (Minimum length - initial length / initial length) X 100
= 11.776
Deviation = Maximum % elongation – Minimum % elongation
= 0.448
USB = Deviation /$\sqrt{3}$
= 0.2587
Considering Rectangular probabilities, Degree of Freedom = ∞

$$(Uc) = \sqrt{U_{RA}^{2} + U_{MB}^{2} + U_{SB}^{2}} \quad \text{where,}$$

$$(Uc) = \sqrt{(0.040)^2 + (0.0075)^2 + (0.2587)^2}$$

=0.2618
Effective degree of freedom (V_{eff}) = $Uc^4/ (U_{RA}^4/ 4 + U_{MB}^4/\infty + U_{SB}^2 /\infty)$
= 2065.32 ≈ ∞
Then coverage factor (k) for Veff ≈ ∞ at 95% confidence level (C.L.) is 1.96

Therefore, expanded Uncertainty (U) = Uc x k
= 0.2618 x 1.96
= 0.5131

2.2.2 Reporting of results:
With coverage factor k = 1.96 for C.L. 95% and Veff = ∞. The % elongation is reported as 12.00 ± 0.5131 (or, 4.275%)
TableNo2.4 Uncertainty Budget for % elongation:-

Sources of uncertainty	Estimated Value	Distribution /Divisor	Sensitivity Coefficient	DOF	Std. uncertainty
U_{RA} repeatability	0.040 mm	Normal /1	1	4	0.040
U_{MB} Vernier Caliper	0.015 mm	Normal, / 2	1	∞	0.0075
U_{SB} Testing speed	0.448 mm	Rectangular /$\sqrt{3}$	1	∞	0.2587
Expanded Uncertainty		K =1.96	-	-	0.5131

2.3 Evaluation of Uncertainty of Measurement in Brinell hardness tester.

Instrument- Brinell Hardness tester (OJ 3952)

Table No 2.5 Observations (BHN)

Xi (BHN readings)	Mean X	Xi – X	(Xi – X)2
262		-0.4	0.16
263		0.6	0.36
262	262.4	-0.4	0.16
263		0.6	0.36
262		-0.4	0.16
			∑ = 1.20

U_1-Uncertainty from repeatability

Standard deviation, SD = 0.54

$$U1 = \frac{SD}{\sqrt{n}} = \frac{0.54}{\sqrt{5}} = 0.24BHN$$

$$DOF = n - 1 = 4$$

U_2- Uncertainty due to accuracy in measurement

It is closeness with which individual readings of 5 readings taken on standard block around the reference value (conventional true value).

Standard block having BHN value 264. Comparing with std block , standard deviation=1.67

U_2 – Uncertainty due to accuracy in measurement:-

$$= \frac{SD}{\sqrt{n}} = \frac{1.67}{\sqrt{5}} = 0.74 \quad BHN$$

$$DOF = 4$$

U_3 -Uncertainty due to standard Block, is 4.35 with k =1.96(From calibration certificate)

U_3= 4.35/1.96 = 2.21 BHN &

DOF = ∞

U_4 - Due to resolution**,**

Procedure to calculate resolution

- Add 0.01 mm (least count measurable on measuring m/c of BHN) to the dia of mean hardness observed
- Calculate new hardness using

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

- The diff between this calculated. BHN and mean value observed is the resolution in hardness units mean reading = 262.4

Dia of this BHN from above formula = 3.75mm

Add 0.01 to 3.75mm , i.e. d = 3.76mm

Therefore new BHN = 260

Resolution = 262.2 – 260 = 2.2

Uncertainty due to resolution = 2.2 BHN

DOF = ∞

Combined uncertainty Uc
U_1=0.24, U_2=0.73, U_3=2.21, U4=2.2
Therefore,

$$U_C = \sqrt{0.24^2 + 0.74^2 + 2.21^2 + 2.2^2}$$

$$U_C = 3.21$$

Effective DOF,

$$V_{eff} = \frac{U_c^4}{\frac{U_1^4}{4} + \frac{U_2^4}{4} + \frac{U_3^4}{\infty} + \frac{U_4^4}{\infty}}$$

$$= 1499.15 \cong \infty$$

Therefore for Veff = ∞, K= 2, at 95.45% CL
Therefore Expanded Uncertainty
U = 2 x 3.21 = 6.42 BHN

2.3.2 Result

Uncertainty associated with measurement of BHN Testing is ± 6.42 BHN i.e. 2.43% at 95.45% Confidence Level and coverage factor, K = 2

Table No.2.6 Uncertainty Budget for BHN:-

Sources of uncertainty	Estimated Value	Distribution / Divisor	Sensitivity Co-eff	DOF	Uncertainty contribution
U_1 Repeatability	0.24 BHN	Normal ,1	1	4	0.24
U_2 Reproducibility	0.74BHN	Normal ,1	1	4	0.74
U_3 std Block	4.35 BHN	Rectangular ,1.96	1	∞	2.21
U_4 Due to resolution	2.2 BHN	Normal ,1	1	∞	2.2
Expanded uncertainty		K=2			6.42

2.4 Evaluation of Uncertainty of Measurement in Rockwell hardness testing.

Instrument: Rockwell Hardness Testing machine
Sample: Standard, test block ID No. 2/4215 for HRB 91.5 U = ± 2.54 HRB at 95% Confidence level.
Table No 2.7 Observations of HRB

Observation	Observed Hardness (HRB)	Average (HRB)	Std. deviation (HRB)
1	92		
2	91		
3	90	91.2	0.8367
4	92		
5	91		

U_{RA} -std. Uncertainty

No. of observation n = 5

Std. error of mean or std uncertainty (H_{RA})

$$= \pm\frac{sd}{\sqrt{n}} = \pm\frac{0.8367}{\sqrt{5}}$$

= $\pm$ 0.3742 HRB = $\pm$ 0.41%

Degree of Freedom = n – 1 = 4

U_{B1}-std. uncertainty contributed due to relative accuracy.

Relative accuracy $= \frac{H_{AV} - H_{std}}{H_{std}} \times 100$ ------------------- (eq.8)

= (-) 0.33%

Where H_{AV} = Average Hardness = 91.2 HRB &

H_{std} = Hardness of test block = 91.5 HRB

Considering rectangular probability distribution

$$U_{B1} = \frac{Relative\ accuracy}{\sqrt{3}} = -\frac{0.33}{\sqrt{3}} = -0.19$$

U_{B2}- std. uncertainty contributed due to test block

Considering rectangular probability distribution

$$U_{B2} = \frac{\pm 2.54}{\sqrt{3}}$$

= $\pm$ 1.47 HRB = 1.61%

Degree of Freedom = ∞

Therefore combined uncertainty

$$U_c = \sqrt{U_{RA}^2 + U_{B1}^2 + U_{B2}^2}$$

= $\pm$ 1.67%

Effective degree of freedom $(V_{eff}) = \frac{U_c^4}{\frac{U_{RA}^4}{4} + \frac{U_{B1}^4}{\infty} + \frac{U_{B2}^4}{\infty}}$

$$= \frac{(1.67)^4}{\frac{(2.41)^4}{4} + 0 + 0} = 1101.0067 \cong \infty$$

Since degree of freedom is more than 30
Coverage factor (K) = 1.96
For $V_{eff} = \infty$ at 95% confidence level.
U = $\pm$ UC x K = $\pm$ 1.67 X 1.96 = $\pm$ 3.27%

2.4.2 Reporting of Result:
With coverage factor K = 1.96 for CL 95% and $V_{eff} = \infty$ the hardness is reported at 91.2 HRB $\pm$ 3.27%

Table No. 2.8 Uncertainty Budget for HRB

Sources X_1	Estimated Value	Distribution / Divisor	Sensitivity coefficient	DOF	Contribution
U_{RA} Repeatability	0.3742	Normal ,1	1	4	0.3742
U_{B1} Relative Accuracy	0.33	Rectangular , $\sqrt{3}$	1	∞	0.19
U_{B2} uncertainty of test block	2.54	Rectangular, $\sqrt{3}$	1	∞	1.47
Expended		K = 1.96			3.27

2.5 Evaluation of Uncertainty of Measurement in Charpy Impact Testing

Instrument: - Impact testing machine
Make - FIE model ITM – 71
Sample - 5 no of V-notch test pieces

Table No 2. 9 Observations of Impact Testing

Observation	Observed Impact Energy (J)	Average (J)	Std. deviation (J)
1	23		
2	24		1.225
3	23	24	
4	26		
5	24		

(U_1)-Std. Uncertainty

No. of observation n = 5

Std. uncertainty (U_1)

$$\frac{Sd}{V\overline{n}} = \frac{1.225}{\sqrt{5}} = \pm.0.54785J$$

Type B std. Uncertainties
Let,
1. Uncertainty Due to Impact velocity - U_2
2. Uncertainty Due to Systematic Error - U_3
3 Uncertainty Due to Machine bias - - U_4
4. Combine Uncertainty - U_C

1. Uncertainty Due to Impact velocity U_2
Let h be the height of pendulum
Impact Energy, E $= W(h - h')$ ---------------------------------- (eq. 9)
and

$$h = \frac{v^2}{2g}$$

Where,
W is the weight of pendulum = 20.932 Kg
Impact velocity v = 5.346 $\pm$ 0.012 m/s
And calculated swing height (h’) of pendulum = 0.3104 m
Hence For maximum velocity i.e. v = 5.346 + 0.012
h = 1.4638
Therefore Maximum Impact Energy, E = 20.932 (1.4638-0.3140)
= 24.14 J
For Minimum velocity i.e. v = 5.346 - 0.012
h = 1.45072 m
Therefore Minimum Impact Energy, E = 20.932 (1.45072 - 0.3140)
= 23.862 J
Hence deviation = Maximum Impact Energy - Minimum Impact Energy
=24.14 - 23.862
= 0.27078 J
Std. Uncertainty Due to Impact velocity -U_2 = $\frac{0.27078}{\sqrt{3}}$
= $\pm$ 0.15634 J

Considering Rectangular probabilities, Degree of Freedom = ∞

2. Uncertainty Due to Systematic Error U_3

Systematic Error associated with test procedure; if specimens are impacted of centre (1 to 2 mm) then energy will be between 0.828 J to 1.65 J.
Therefore uncertainty associated with systematic error

$$U_3 = \frac{1.65 - 0.828}{2\sqrt{3}} = 0.2373J$$

Considering Rectangular probabilities, Degree of Freedom = ∞

3. Uncertainty Due to Machine bias U4

Machine bias, b = $\overline{V} - \delta_{systematic} - R$ ------------------------ (eq. 10)

Where, sample mean $\overline{V} = \frac{\sum V}{n} = 24$

$\delta_{Systematic}$ is the errors due to systematic effects of indirect verification = 0.113 J.
R – Is the certified reference valve for testing material = 24.8362 J.
b = 24 – 0.113 – 24.8362
= - 0.9492
Uncertainty due to machine bias,

$$U_4 = \frac{0.9492}{\sqrt{3}} = 0.54802J$$

Considering Rectangular probabilities, Degree of Freedom = ∞

Combined Uncertainty (U_C) is given by

$$(Uc) = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_4^2}$$

Where
1. Uncertainty due to repeatability - U_1
2. Uncertainty Due to Impact velocity - U_2
3 Uncertainty Due to Systematic Error - U_3
4 Uncertainty Due to Machine bias - - U_4
5. Combine Uncertainty - U_C

$$(Uc) = \sqrt{0.54785^2 + 0.15634^2 + 0.2373^2 + 0.54802^2}$$

(Uc) = 0.8253 J
Effective degrees of freedom

$$V_{eff} = \frac{U_C^4}{\frac{U_1^4}{4} + \frac{U_2^4}{4} + \frac{U_3^4}{4} + \frac{U_4^4}{4}}$$

$$V_{eff} = \frac{0.79214^4}{\frac{0.54785^4}{4} + \frac{0.15634^4}{\infty} + \frac{0.2373^4}{\infty} + \frac{0.54802^4}{\infty}}$$

$$= 20.60 \approx 21$$

Hence for V_{eff} = 21 at 95 % confidence level coverage factor, k = 2.080
Therefore expanded uncertainty
U = Uc X k
U = 0.8253 X 2.08 = 1.7166 J

2.5.2 Reporting of results:
With coverage factor k = 2.08 for C.L. 95% and V_{eff} = 21 the impact energy in charpy impact testing is reported as 24.00 ± 1.7166 (or, 7.153%)

Table no. 2.10 Uncertainty Budget for Impact Testing

Sources of uncertainty	Estimated value	Distribution/ Divisor	Sensitivity Coefficient	DOF	Standard Uncertainty
U1 Repeatability	0.54785 J	Normal ,1	1	4	0.54785
U2, Impact velocity	0.27078 J	Rectangular $\sqrt{3}$	1	∞	0.15634
U3 Systematic error	0.411 J	Rectangular $\sqrt{3}$	1	∞	0.2373
U4 Machine Bias	0.9492 J	Rectangular $\sqrt{3}$	1	∞	0.54802
Expanded Uncertainty		k=2.08			1.7166 J

3. **Result-Comparative Analysis**

In case of material testing lab of ordnance factory, Nagpur above five tests are performed on various materials. All five tests may or may not be performed on every material as per requirement of customers. Objective of the work is to check the quality performance of lab where it is affected by every individual test. In comparative analysis, it shows what factor will affect the quality of lab and its quantified effect in total uncertainty calculation of lab.

Table No 3.1 Comparitive analysis of impact of each parameter on all the testing methods.

sources of Uncertainty	Type 'A'		Type 'B'							
	Repeatability	Reproducibility	Measuring instrument	Zeroing	Testing Speed	Relative accuracy	Test specimen	resolution	Systematic error	Machine Bias
Test										
Tensile	0.025	-	0.0338	0.156	0.115	0.469				
% Elongation	0.077		0.0146		0.504					
Brinell Hardness	0.037	0.115	-	-	-	-	0.344	0.342		
Rockwell Hardness	0.111					0.058	0.44			
Charpy impact	0.319				0.091				0.138	0.319

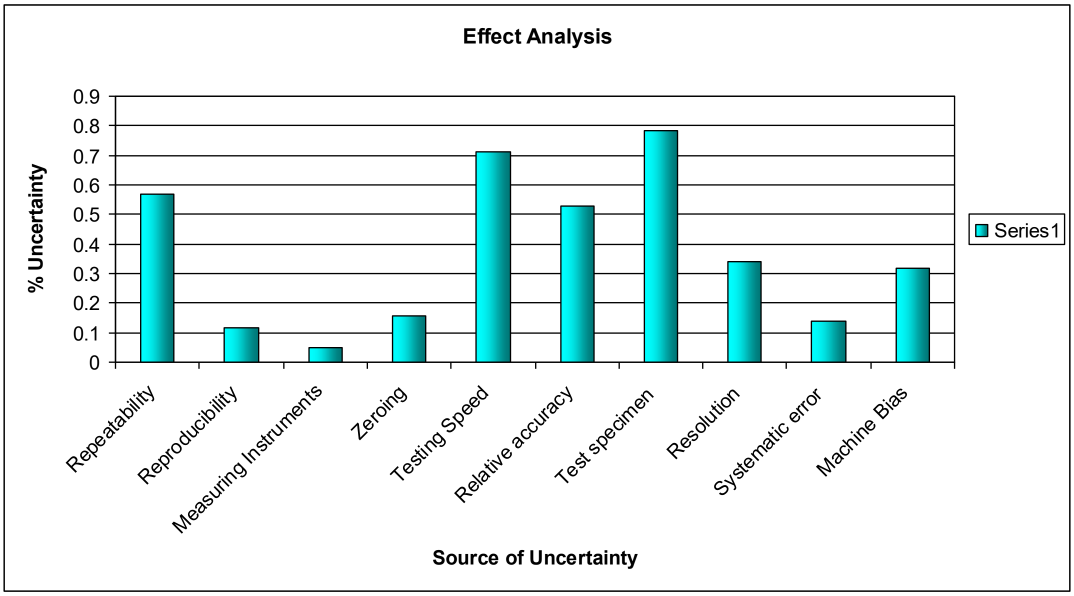

Fig 3.1 Comparitive analysis of impact of each parameter on all the testing methods.

The impact of standard test specimen and testing speed on the overall uncertainty of material testing lab is on higher side with compare to other sources of uncertainty on the other hand measuring instruments contributes in very less manner.

Conclusion

1. From the above results it clear that the influence of uncertainty value in Impact Testing is on higher side with compare to other Testing procedures.
2. The impact of test specimen and testing speed on the overall uncertainty of material testing lab is on higher side with compare to other parameters.
3. This way, the result will be statistically more robust, which will also validate the extension of this methodology for Fatigue and Creep Testing as a future research works.
4. Even if the result of the measurement is not perfect, it is possible to obtain reliable information, since the result of the measurement is associated with its respective uncertainty.
5. Based on the current results, we can easily concentrate on parameters which are having major impact on the final result, for improving the testing procedure
6. Every measurement instrument, no matter how optimized is its acting capacity, it is not exempt of provoking mistakes when of its use, the tensile testing rehearsals can supply reliable information of the mechanical properties of the rehearsed materials

References

1. Mandavgade N.K., Jaju S.B, Lakhe R.R.(2015)"Assessment of Qualitative Factors Affecting Uncertainty Measurement Using AHP" published in International Journal of Industrial and system engineering,ISSN: 1748-5045 by Inderscience publication, Vol. 21,No. 3,2015 PP.277-301.
2. BIPM/IECIIFCC/ISO/OIML/IUPAC,ISBN 92 67 101889 ,1993-95- Guide to the expression of uncertainty in measurement.
3. Mandavgade, N. K. , Jaju, S. B. and Lakhe, R.R., Uncertainty Of Measurement : Literature Review And Some Issues, Industrial Engineering Journal (2018), Volume 10 (8), doi: https://doi.org/10.26488/IEJ.10.8.54.
4. Mandavgade N.K, Jaju S.B.,Lakhe R.R, "Evaluation of Uncertainty of Measurement in Tensile Testing" ISSN:0976-9293 Int J Engg Techsci Vol 2(2) 2011,221-224

5. Da Silva Luiz Roberto Oliveira (2004)–"Evaluation Of The Uncertainty Of Measurement of Mechanical Properties on the Tensile Testing "Simposio de Metrología 2004 25 al 27 de Octubre,
6. JCGM 100:2008 GUM 1995 with minor corrections Evaluation of measurement data Guide to the expression of uncertainty in measurement.
7. Eurolab Technical report 1/2002 June 2002 on measurement Uncertainty in testing, Eurolab Germany.
8. Stephanie Bell- "A Beginner's Guide to Uncertainty of Measurement" Centre for Basic, Thermal and Length Metrology.
9. B.V.Ramana (2007) "Text Book of Higher Engineering Mathematics" Tata McGraw-Hill comp. Limited, New Delhi.
10. Mandavgade N.K., Jaju S.B, Lakhe R.R. (2014) "Estimation of Machine Interference Existence Using Control Chart Approach" published in International Journal of Instrumentation Technology by Inderscience publication, Int. J. Instrumentation Technology,ISSN: 2043-7862, Vol. 1, No. 3, 2014, PP.189-211.
11. Mandavgade N.K., Jaju S.B, Lakhe R.R.(2012), "Evaluation of Uncertainty of measurement of Automatic Tan Delta and Resistivity test set for Transformer oil" published in International Journal of Metrology and Quality Engineering (IJMQE) ISSN:, 2107-6847, Cambridge University journal volume 3, issue 1, 39–45.
12. Mandavgade N.K., Jaju S.B, Lakhe R.R.(2012),"Identification of uncertainty sources in measurement–a methodology" published in journal of measurement science and technology, China Vol.3, Issue 4, Sum No.12 Dec 2012 pp 307-312.
13. W.Gabauer –"Estimation of Uncertainty in Hardness Measurement" Standards Measurement & Testing Project No. SMT4-CT97-2165 , AUSTRIA, Issue 1,September 2000.