

Modified Erichsen Cupping Test for Copper, Brass, Aluminium and Stainless Steel

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Abstract—Modified Erichsen cupping test is one of the currently used formability test, which evaluate the ability of sheet metal to be formed into useful components successfully. The formability test index is identified as one of the most important formability test result that could be used on a routine basis by industry for grading, selecting and sorting of incoming sheet metals for manufacturing of various components. In older Erichsen test, the results obtained were uncertain, as there was no control of the clamping force. The test consist of clamping a metal test piece under controlled pressure between retaining ring and die and pressing the test piece into the die by means of a penetrator having a spherical head, until the end point (fracture) is reached. The depth of penetration there by obtained is measured an Eserichsen index (JE). Practical ERICHSEN CUPPING TEST equipment have been repeated for different material specimens of different thickness using different lubricants like castor oil, lanthax grease and general multi purpose grease are found .it observed from the present experiment that in general the Erichsen number is influenced by the type of lubricant. The Erichen number increase with an increase in the thickness of the sheet metal.

Keywords—Materials: Aluminium, Brass, Copper, Stainless Steel; Lubricants: Castor Oil, General Multi-purpose Grease, Lanthax Grease

Abbreviations—Dry Friction Condition (DFC), General Multi Purpose Grease (GMPG)

I. INTRODUCTION

FORMABILITY is a measure of the ability of a sheet made to be stamped or formed successfully into useful components without developing any failures. The common failure encountered during sheet metal forming is fracturing, wrinkling, puckering; shape distortion, loose metal etc. formability is not easily quantified as it depends on several interacting factors. Material flow properties, ductility, die geometry, die materials, lubrication conditions and press speed contribute to the success or failure of the formed sheet metal components to varying degree in an inter dependent manner. Formability should be viewed more as „system“ parameters, as it is a function of the sheet metal that is being formed, the process conditions, the forming press, and the component shape [Stuart P Keeler, 1971].

1.1. Need for Formability Test

The basic forming characteristics of sheet metals are obtained to some extent even by the simple intrinsic mechanical properties obtained from tensile tests. A high strain hardening exponents related to the ability of sheet material to undergo

large uniform strains during biaxial stretching operations [Gronostajski & Banasiak, 1976]. Lower yield strength gives lower spring back and facilitates shape attainment in lightly formed parts. A high value of the strain rate sensitivity index, also, improves stretch ability by delaying the onset of localized necking, and many other properties are influenced. It is, therefore, essential to have tests that simulate the processing conditions and deformation modes existing during the industrial forming of sheet metal components [Datsko, 1966]. Such tests, called as formability tests [Narasimha & Nandedkar, 1996]. Would allow better quantification of the formability of sheet metals, taking into account the synergistic interaction of sheet metals intrinsic properties and the processing conditions existing during processing operations. It is to be noted that most of the formability tests do not take into account the influence of the forming equipment itself. Further, in single formability test can describe the formability for all types of stamping applications. It is for this reason that various researchers have developed several formability tests.

1.2. Formability of Sheet Metals

Sheet metal forming is the process of converting a flat sheet into a part of desired shape with out fracture or excessive localized thinning. The process may be simple, such as a bending operation, or sequence of very complex operations such as those performed in high-volume stamping plants, in the manufacture of most large stampings, a sheet metal blank is held on its edges by a blank-holder ring and is deformed by means of a punch and die. The moment of block into the die cavity is controlled by pressure between the upper and lower parts of the blank-holder ring. Sheet metal forming operations are so diverse in type, extent, and rate that no single test provides an accurate indication of the formability of a material in all situations. However, knowledge of material properties and careful analysis of the various types of forming involved in making a particular part are indispensable in determining the probability of successfully part production and in developing the most efficient process.

1.3. Effect of Material Properties on Formability

The properties of sheet metals vary considerably, depending on the base metal steel, aluminium, and copper and so on, allowing elements present, processing, heat treatment, gage and level of cold work. In selecting material for a particular application, a compromise usually must be made between functional properties required in the part and the forming properties of the available materials. For optimal formability in wide range of applications, the work material should;

1. Distribute strain uniformly
2. Reach high strain levels with out necking or fracturing
3. With stand in-plane compressive stresses with out wrinkling
4. With stand in- plane shear stresses with out fracturing

II. PRINCIPLE OF TEST

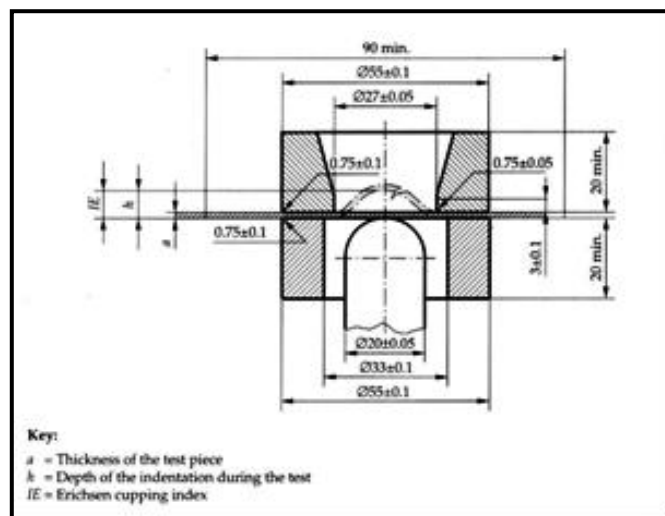


Figure 1 – Working Principal of Erichsen Cupping Test (All Dimensions are in mm)

The Erichsen cupping test is a ductility test, which is employed to evaluate the ability of metallic sheets and strips

to undergo plastic deformation in stretch forming [Hawtin et al., 1963; Hawtin & Parkes, 1970]. The test consists of forming an indentation by pressing a punch with a spherical end against a test piece clamped between a blank holder and a die, until a through crack appears. The depth of the cup is measured.

2.1. Types of Formability Test

Formability tests are of two basic tests, intrinsic and simulative intrinsic tests measure the basic characteristic properties of materials that can be related to their formability. Simulative test subject the material to deformation that occurs in a particular forming operation.

2.2. Testing Equipment

1. The design of the equipment shell is sufficiently robust so as to prevent appreciable deformation of any of the parts during the test.
 - a. The penetrator should not turning during the test
 - b. The construction of the machine should be such that it is possible to determine accurately the moment vent rupture commences.
 - c. The surfaces of the retaining ring and of the die in contact with the test piece should be Plain, polished and parallel to each other and perpendicular to the axis of moment of the penetrator
2. The dimensions and tolerances shall comply with those as shown in figure 1. the center of the Spherical part of the penetrator, during its entire travel in use, shall not be eccentric by More than 0.1mm with the test piece during the test.
 - a. The working surface of the penetrator shall be spherical and only this spherical Portion shall be in contact with the test piece during the test.
 - b. The Vickers hardness of the working surface of the die, the retaining ring and the Penetrator should be at least 750 HV.

2.3. Test Pieces

Where the dimensions of the product permit, the test piece shall be flat and of such that the center of any impression is not less than 45mm from any edge of the test piece, and not less than 90mm from the center of the nearest impression. If this is not possible, special agreement may be reached between the parties concerned [Groove, 1984].

The cutting of the test piece shall not produce on the edges any burr or distortion which would interfere with being placed in the apparatus. The test piece before test shall not be submitted to any hammering or hot or cold working.

2.4. Test Procedure

1. In all cases, the ambient temperature at the time of the test shall be reported
2. Determine the thickness of the test piece to the nearest 0.01mm

- Before operating the machine, lightly grease the two phases of the test pieces and the penetrator with graphite grease. Recommended characteristics of the grease used for testing machine are given below.
- Press the test piece between the retaining ring and the die. It is preferable that the gripping load be approximately 1000 kg. Bring the penetrator with out shock in contact with the test piece, but not pressing it, thus deterring the point from which to measure the depth of penetration.
- Proceed with the cupping, which should take place with out jerking and at a speed between 5 to 20 mm per minute. Towards the end of the operation, reduce this speed to the vicinity of the lower limit, in order to determine accurately the moment when rupture commences.
- By the convection, rupture commence when a crack appears through the full thickness of the test piece and sufficiently open to allow daylight to pass through all or open of its length.
- Generally the commencement of ruptures accompanied by a drop in the force supported by the test piece and some times by a perceptible noise.
- Stop the test at this point and determine by direct reading on the apparatus, with an accuracy of 0.1mm, the depth of the penetration of the penetrator. This depth expressed in millimeters gives a number which is cupping number JE.
- The drop in the force may also be considered as the criterion of the end of the test, but in cause of dispute the appearance of the crack shell be used.

III. RECOMMENDED CHARACTERISTICS OF GREASE

The results of the tests are influenced by the type of the grease used, particularly. When the lubricating properties of the grease are inadequate. The grease would consist of calcium soap, refined mineral oil graphite, free from corrosive matter. Grit resin, waxes and fillers with the following characteristics:

Worked penetration: 250 to 280
 Free acidity [percent oleic acid]: 0.2 Max
 Free alkalinity [percent Ca OH₂]: 0.3 Max
 Water content [percent by weight]: 0.5 to 1.2
 Graphite content [percent by weight]: 23 to 28
 The graphite should be flask graphite.

Conforming to the following Requirement:

Average particle size [mm]: 0.3 Max
 Maximum particle size [mm]: 0.5
 Ash [percent by weight]: 4.5 Max

The mineral oil should confirm to the following requirements:

Viscosity at 37.8 C [centi stroke]: 100 to 200
 Closed flash point: 177 c Min
 Ash [percent by weight]: 0.01 Max
 Neutralization value [mg.KOH/g]: 0.1 Max

IV. EXPERIMENTAL RESULTS

Checking of scatter in modified Erichsen cupping test results [Sastry, 1977; Gajalappa, 2000].

Material: Mild steel

Condition: as rolled

Lubricant used: Lanthax Grease

Table 1– Checking of Scatter in Modified Erichsen Cupping Test Result

Thickness in mm				
t=0.5	t=0.8	t=1.0	t=1.25	t=1.45
9.5	9.8	9.5	11.3	11.8
6.6	9.6	9.9	11.0	11.85
9.7	10.1	10.2	11.35	12.0
9.3	9.95	10.0	11.35	12.0
9.1	10.0	10.1	11.2	12.12
9.15	9.9	10.15	11.5	12.3
Avg= 9.39	Avg= 0.87	Avg= 9.97	Avg= 11.28	Avg= 11.99
Scatter= 6.59	Scatter= 6.3	Scatter= 6.84	Scatter= 4.09	Scatter= 4.24

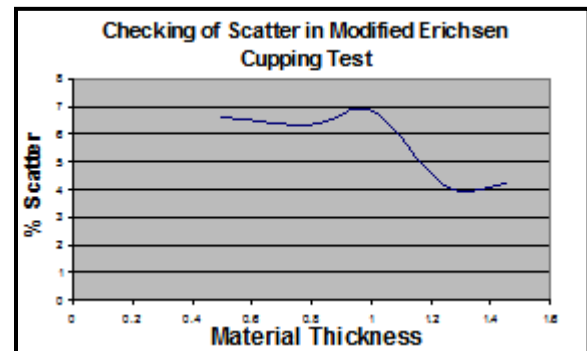


Figure 2 – Thickness Vs Scatter

Summary of Experimental Result from Modified Erichsen Cupping Test with Dry Friction Condition and Lubricated Conditions

Table 2 – Material: Copper / Condition: As Rolled

Sheet Metal Thickness in mm	Erichsen Number [JE]				Increase in JE with the Usage of GMPG from DFC	Increase in JE with the Usage of GMPG from Lanthax Grease	Increase in JE with the Usage of GMPG from Castrol oil
	Lubricated Conditions						
	Dry Friction Condition [DFC]	Lanthax Grease	Castor Oil	General Multi Purpose Grease [GMPG]			
0.30	5.88	6.40	6.00	7.00	19.05	9.38	16.6
0.50	7.00	7.50	7.20	7.90	12.86	5.33	9.72
0.80	7.34	8.00	7.84	8.82	12.81	3.50	5.61
1.00	7.64	8.40	8.20	8.50	11.26	1.19	3.66
1.20	9.42	9.90	9.74	10.0	6.16	1.19	2.67
1.30	10.6	11.0	10.9	11.1	4.72	1.19	1.83

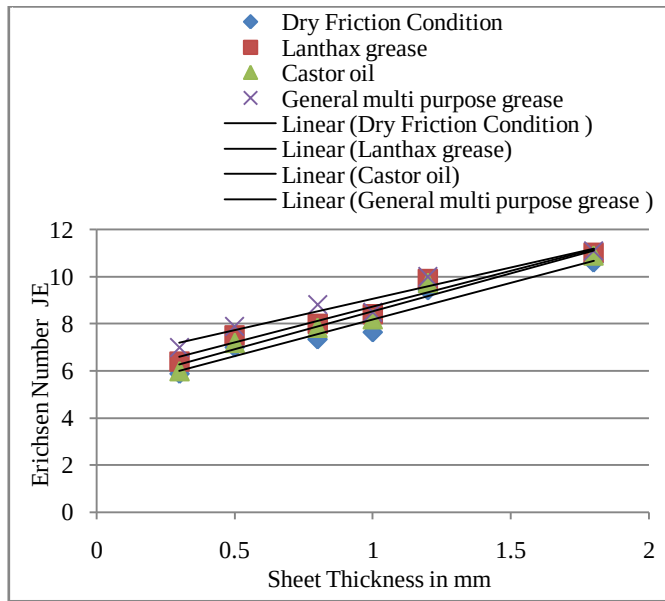


Figure 3 – Erichsen Number Vs Sheet Thickness for Copper

Table 3 – Material: Brass / Condition: As Rolled

Sheet Metal Thickness in mm	Erichsen Number [JE]				Increase in JE with the Usage of GMPG from DFC	Increase in JE with the Usage of GMPG from Lanthax Grease	Increase in JE with the Usage of GMPG from Castrol oil
	Lubricated Conditions						
	Dry Friction Condition [DFC]	Lanthax Grease	Castor Oil	General Multi Purpose Grease [GMPG]			
0.30	7.20	7.58	7.40	8.28	15.00	9.23	11.28
0.50	8.12	8.72	8.64	9.26	14.04	6.12	7.17
0.80	8.62	9.44	9.26	9.82	13.92	4.03	6.05
1.00	10.00	10.26	10.18	10.44	4.40	1.75	2.55
1.20	10.12	10.34	10.26	10.52	3.95	1.74	2.53
1.80	10.38	10.56	10.44	10.68	2.89	1.14	2.30

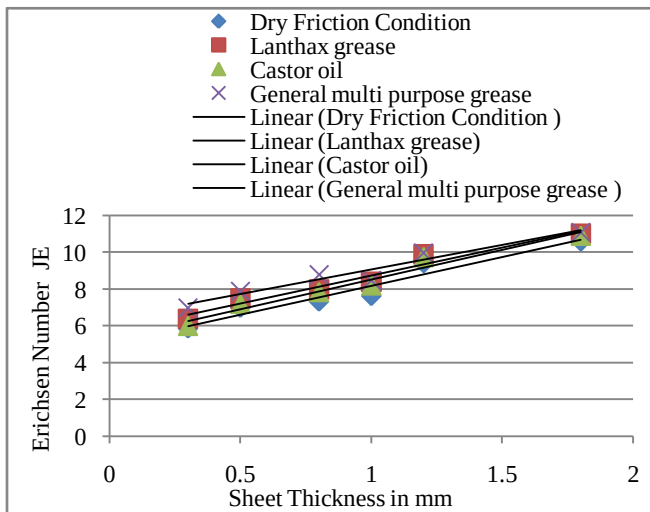


Figure 4 – Erichsen Number Vs Sheet Thickness for Brass

Table 4 – Material: Stainless Steel / Condition: As Rolled

Sheet metal Thickness in mm	Erichsen Number [JE]				Increase in JE with the Usage of GMPG from DFC	Increase in JE with the Usage of GMPG from Lanthax Grease	Increase in JE with the Usage of GMPG from Castrol oil
	Lubricated Conditions						
	Dry Friction Condition [DFC]	Lanthax Grease	Castor Oil	General Multi Purpose Grease [GMPG]			
0.3	9.64	10.54	10.48	11.8	12.41	11.95	12.59
0.5	11.5	12.0	11.64	12.66	10.91	5.5	8.76
0.8	12.14	12.74	11.92	12.92	6.43	1.41	8.39
1.0	12.28	12.81	12.41	12.98	5.7	1.33	4.59
1.2	12.5	12.84	12.74	13.0	4.0	1.2	2.04
1.8	12.66	13.0	12.92	13.14	3.79	1.08	1.7

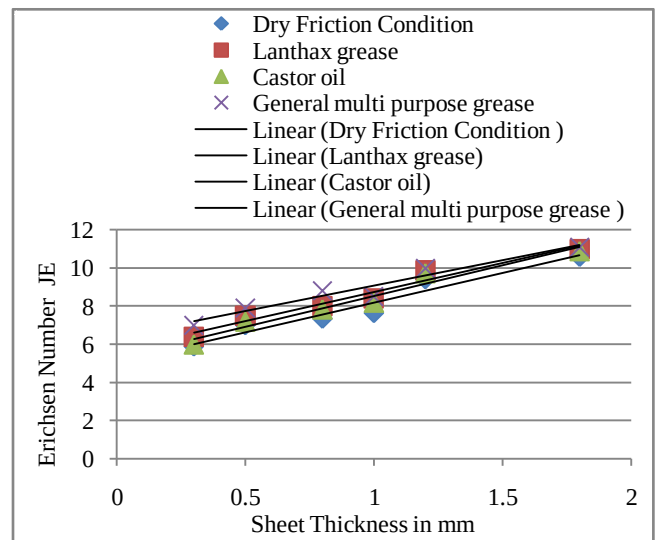


Figure 5 – Erichsen Number Vs Sheet Thickness for Stainless Steel

Table 5 – Material: Aluminium / Condition: As Rolled

Sheet Metal Thickness in mm	Erichsen number [JE]				Increase in JE with the Usage of GMPG from DFC	Increase in JE with the Usage of GMPG from Lanthax Grease	Increase in JE with the Usage of GMPG from Castrol oil
	Lubricated conditions						
	Dry Friction Condition [DFC]	Lanthax Grease	Castor Oil	General Multi Purpose Grease [GMPG]			
0.3	5.22	5.94	5.52	6.2	18.77	4.38	12.32
0.5	6.3	7.12	6.8	7.4	17.46	3.93	8.82
0.8	7.92	9.1	8.64	9.3	17.42	2.2	7.64
1.0	9.12	9.82	9.6	10.0	11.4	1.83	4.16
1.2	10.0	10.26	9.98	10.38	3.8	1.17	4.0

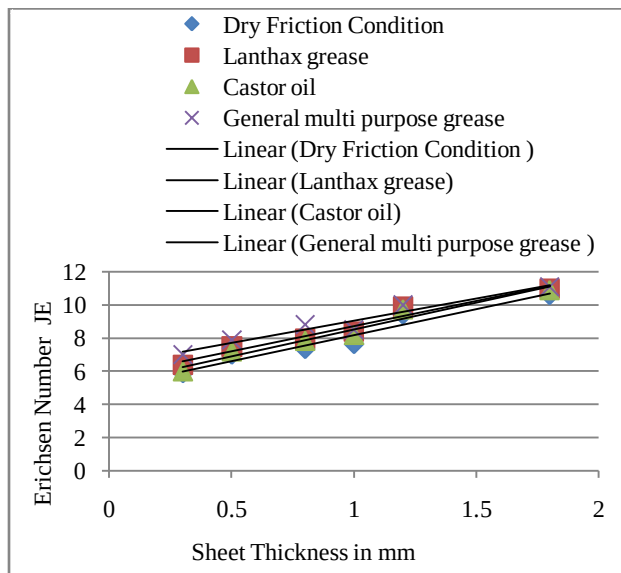


Figure 6 – Erichsen Number Vs Sheet Thickness for Aluminium

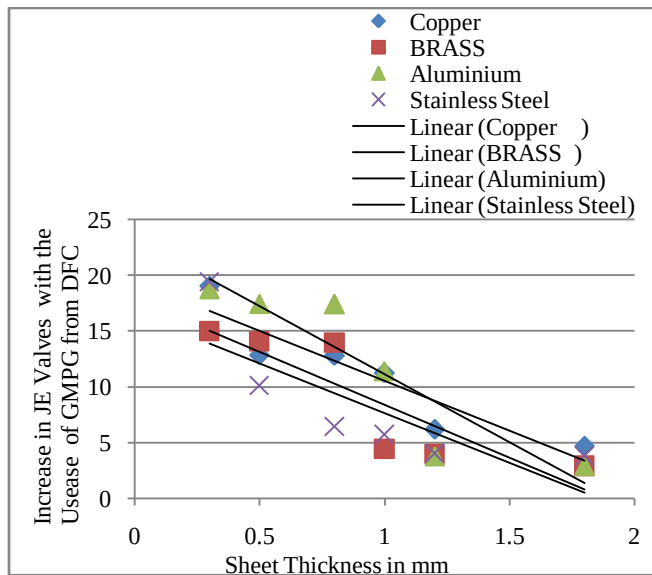


Figure 7 – Present Increase in JE Valves with the Usages GMPG from DFC Vs Sheet Metal Thickness

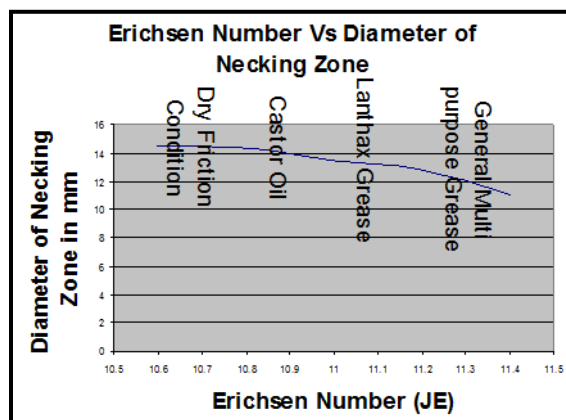


Figure 8 – Erichsen Number Vs Diameter of Necking Zone

V. DISCUSSION AND CONCLUSION

1. Six samples were tested from each sheet metal thickness in the case of mild steel. A difference of 0.64 between maximum and minimum Erichsen index values corresponding to 1.0mm sheet metal thickness is obtained when lanthax greased is used this shows good consistency (table-1).
2. In general it is concluded that the formability index value from the Erichsen cupping test increases with increase in sheet metal thickness for all the metals tested in the present work, (Table no 2 & 3) that is copper, brass. These trends indicate that thin sheet is more difficult to be formed compared to thick sheet.
3. In the case of copper and brass it is observed that the theoretical Erichsen number value estimated from the empirical relation suggested by the earlier research works are found to be slightly grater than the practical value obtained from the present work. The average difference the theoretical and practical Erichsen index value is roughly 1 to 1.5.
4. In general it is observed that for all materials tested in the present work the percentage change in the Erichsen index valve,(between dry friction condition and lubricated condition with general multipurpose grease) decreases with an increase in sheet metal thickness , a lubricated condition with general multi-purpose grease gives highest value for Erichsen number compared to either dry friction condition or lubricated conditions with other lubricants like castor oil and lanthax grease.
5. The ring shaped zone of localized thinning gives an indication of the position of the rupture during the test. Diameter of this ring shaped zone measured for the specimens used in the Erichsen test. A distinct relationship is found to exist between the position of the rupture and the Erichsen cupping depth. For example in the case of mild steel 1.3mm thickness (Figure 8)

It is observed that the radial distance between the crack position (indicated at the diameter of the necking zone, d) and the axis of the cup decrease with an increase in the effectiveness of the lubricant (i.e as the friction force between the punch and the sheet metal decrease). The figure also shown clearly that for dry friction condition, the fracture also located farthest from the center of the cup i.e.7.25mm($145/2=d/2$)and in the case of general multi-purpose grease, the radial distance between fracture position and cup axis decreases to a minimum valve of 5.55mm ($11.1/2=d/2$). It is also known from the previous conclusion, made in he present test that the general multi-purpose grease has been adjudged as the best lubricant, which has consistently given highest Erichsen cupping number

Values for various thickness and sheet metals tested. Therefore, it can be reasoned out that the radial gap between the fracture position and the axis of the cup gives an indication about the effectiveness of the lubricant in obtaining

higher Erichsen number value and helps us during the selection of paper lubricants for the test and also during practical forming process. In a theoretical case with zero friction condition the fracture is expected to be positioned exactly over the center of the cup.

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