Analysis of Shear Edge Quality for Different Punch Velocities in Micro-Blanking Process

Aida Mahmudah[1], Gandjar Kiswanto[1,2], and Dedi Priadi[1,2]
[1]Mechanical Engineering Department, Universitas Indonesia, Depok, Indonesia
[2]Metallurgy and Materials Engineering Department, Universitas Indonesia, Depok, Indonesia
Email: gandjar_kiswanto@eng.ui.ac.id

***Abstract*—A die clearance is the main factor that influence a proportion of a shear edge. With a larger die clearance, the shear edge will be more irregular. A good blanking quality has a shear edge with a large portion of shear zone, i.e. a smooth and shiny area, and small portions for the rest. In this research, the investigation was held to study about the shear edge occurrence on micro-blanked-part with a specified die clearance and a varying punch velocities. The investigations of the shear edge in micro level provide more distinct difficulties comparing with the macro level due to the restricted size of micro-part. The experiment applied 0.5 mm/s and 5 mm/s of punch velocities in blanking of aluminum and copper foil with 0.1 mm thickness. The die clearance was determined at 0.033 mm. The material foils were set at longitudinal and transverse direction to observe the influence of the rolling direction to the shear edge proportion. The result showed that with a higher punch velocity, the shear zone portion became larger. It is concluded that with the specified die clearance, the shear edge quality can be improved if higher punch velocity was applied.**

***Index Terms*—shear edge, punch velocity, micro-blanking process**

I. Introduction

Nowadays, the micro-devices are required in a large volume. So that a high demand for micro parts should be fulfilled with an appropriate manufacturing technology. In producing 2D-blanked-components, lithography technology delivers a high-quality part. However, we can use micro blanking since a lower cost production, wider material use, better material integrity, and excellent material properties. Therefore, the micro-blanking is still needs to be elaborated [1].

Blanking is one of basic shearing process configurations in micro-sheet-metal forming. To the contrary with piercing process, the cut out is of interest. During the process, the material separation will occur in a cutting zone if the material shear stress gets beyond the ultimate shear strength [2]. Since the effect of scaling down changes the deformation behavior of the blanking process, some experiments have been held to investigate it. The parameters that influence the quality of blanked part are punch-die clearance, material properties, punch velocity, cutting wear, lubrication, tool alignment, etc. [3].

In micro-blanking, the used material should be prescribed more detailed than at macro-level by the microstructures and grain boundary properties. Fu *et al*. [4] stated that if an average of grain size approaches the material thickness, the blanking behavior will be affected obviously. With the increasing of grain size, the grain boundary hardening decrease. Hence, the flow stress, the fracture strain and the number of micro-voids on the fracture surface decrease with the decreasing of t/d (thickness/average grain size) ratio. Besides, the deformation process in micro-forming can be accomplished only by a few slip systems activation.

The deformation behavior of micro blanking process is also influenced by the ratio of blanking clearance to the average grain size, c/d. The ultimate shear strength Ks reaches the maximum value when c/d =1, because of the slip and coordination of the grain are more firmly joined with the decreasing of the grain's number [5].

In micro-blanking, a shear edge of the blanked part is an indicator of the quality of the part. To have a high part quality, the shear edge should be have a large portion of shear zone.

Most of the blanking process investigations only focused on shearing behavior related to the material properties and a few of tool parameters. Whereas due to manufacturing errors still appear in tool fabrication, the process parameters also become important in obtaining a high-quality product. Grűnbaum *et al*. [6] conducted a study about a high cutting speed influence to the blanked-part quality at macro level and found that the quality of part edge improved when a higher cutting speed was applied.

Due to the restricted size, the experiments of the shear edge in micro level encounter much more difficulties than in macro level. However, it still need to be investigated to improve the part quality in micro-blanking process. In our previous research about the influence of die clearance and punch velocity in micro-blanking process, it was found that a higher punch velocity was significantly affect the blanking-part from brass foil [7]. However, the investigation was not held in the cross section area, so that the shear edge portion could not be observed.

In this study, a new experimental study of a micro-blanking process is conducted to investigate the influence

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of punch velocity to the shear edge portion. The experiment use aluminum and copper foil with 0.1 mm thickness.

II. Experimental Equipment and Method

A. Micro-forming Machine

In the previous study, a micro forming machine with a capacity of 5 kN was developed. The machine was driven by an Oriental servo motor NX940MS-PS10-3, which transferred the mechanical force to the ram using ball screw and change rotational motion into translational one. The design was conducted using VDI 2222 Design Method and Advanced Decision Matrix Method based on the Robust Decision Making [8]. The assembled micro forming machine is shown in Fig. 1. The main components that construct micro forming machine were lower and upper base, guide pillar, upper and lower bolster, ram, motor spacer, ball screw, and servo motor.

The working principle of this machine was driven by the servo motor (a) that transferred force to rotate ball screw (b). The ball screw drove ram (c) to move linearly and control stroke motion. Movement was directed by guiding set (d). The tooling system (punch and dies) was mounted on the upper and lower bolster (e1 and e2).

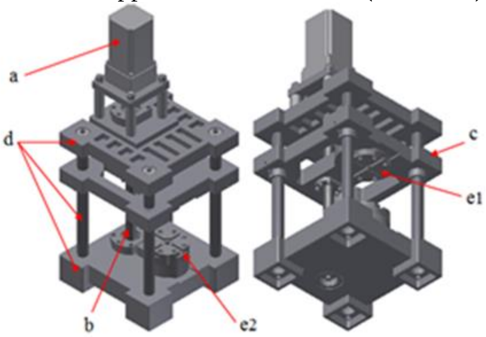


Figure 1. 3D model and detailed drawing of μ-Forming machine 5kN. Sub-Function of micro forming machine; a). Servo motor, b). Ball screw. c). ram, d). Frame and guiding set, e). Bolster.

TABLE I. μ-Forming Machine 5kN Specification

Maximum Load Capacity	[kN]	5
Servo motor: NX940MS-PS10-3		
Max holding torque	[Nm]	34.3
Moment of rotor inertia	[$kg{\cdot}m^2$]	$0.314{\cdot}10^{-4}$
Resolution	[P/R]	100 – 100000*)
Gear ratio		10
Allowable speed range	[rpm]	0 to 300
Backlash	[°]	0.25
Resolution	[μm]	0.5 to 500
Working area	[mm]	L x w x h **) 100 x 200 x 120
Average deviation linear motion	[μm]	0.5 ÷ 4

*) factory setting 1000)
**) recommended at h = 70 to 90)

Strength analysis of the machine structure was performed on a static and maximum loading conditions since the operating condition will be performing at a low speed and load. Machine performance was measured by analyzing geometrical tolerances of the machine, movement, and stroke resolution. The analysis showed that the machine was reliable to conduct the micro-forming process. The following Table I illustrates the specification of the micro forming machine.

B. Micro-V bending Tool

Blanking is a shearing operation which the cut out is of interest. In this research, the blanked part dimension was *t* x 1 x 7.4 mm, with *t* was representative of material thickness. The tool was designed with four blanking posts so that it could produce four blanking parts in one stroke. To attain a good material gripping, a polyurethane stripper was used (Fig. 2).

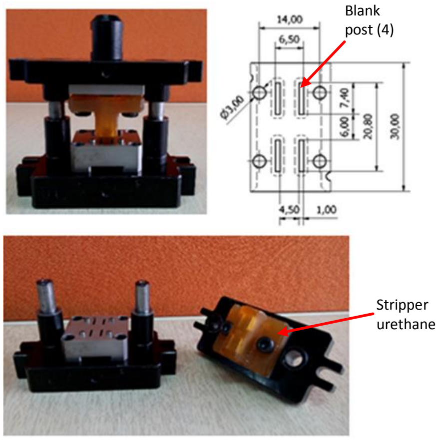


Figure 2. Micro blanking tool.

In blanking operation, a gap between the punch and die, i.e. clearance, is a major factor that influences blanked-part quality. In this research, the clearance was 0.033 mm. One piece loading method was applied, and pin locating was selected to obtain tool manufacturing simplicity.

Generally speaking, the minimum material requirements for the main component, i.e. punch and die, can be fulfilled by tool steel material, while the others can use machinery steel. Mechanical properties of the micro-forming tool components can be seen in Table II below. For groups of the tool steel, SKD 11 (AISI D2) was used while for the machinery steel S45C steel (AISI 1045) was used.

TABLE II. Mechanical Properties of S45C and SKD1

		Cold Work ToolSteel (D2/SKD11)	Machinery Steel (1045/S45C)
Ultimate tensile strength	[MPa]	-	569
Yield Strength	[MPa]	1650	343
Elongation	[%]	-	20
Modulus of Elasticity	[GPa]	209.9	205
Poissons Ratio		-	0.29
Machinability	[%]	-	55
Shear Modulus	[GPa]	-	80

C. Material Characterization

Aluminum and copper with 0.1 mm thickness were selected as material specimens. Table III and Table IV show the chemical composition for the aluminum and copper foil, respectively. To investigate the influence of material anisotropy to the shear edge portion, blanking process is conducted in longitudinal and transverse with respect to rolling direction, i.e. 0° and 90°. Table V and Table VI show the mechanical properties for the aluminum and copper foil. The surface roughness of materials which was measured by using Surfcom 2900 SD3 are showed in Fig. 3.

The chemical composition was obtained from Optical Emission Spectrometer, while the tensile test was held on Servopulser Shimadzu 20T. No pre-heated process conducted to the material since the experiment observed the material with the given properties.

TABLE III. CHEMICAL COMPOSITION OF THE ALUMINUM FOIL

Fe (%)	Cr (%)	Zn (%)	Ni (%)	Cu (%)	Pb (%)	Al (%)
1.51	0.04	0.02	0.02	0.01	0.01	Bal.

TABLE IV. CHEMICAL COMPOSITION OF THE COPPER FOIL

Cu (%)	Zn (%)	Pb (%)	Sn (%)	P (%)	Mn (%)	Fe (%)	Ni (%)
98.5	0.191	0.024	0.046	0.195	0.003	<0.005	0.111
Si (%)	Mg (%)	Cr (%)	Al (%)	Ag (%)	Co (%)	Bi (%)	Sb (%)
0.042	0.001	0.003	0.009	0.006	0.044	0.213	0.027

TABLE V. MECHANICAL PROPERTIES OF ALUMINUM FOIL

		a)*	***b***)*
Tensile Strength	[MPa]	120	108
Yield Strength	[MPa]	76	61
Elongation	[%]	16.2	15.7

*) Tensile test in (*a*) longitudinal and (*b*) transverse direction

TABLE VI. MECHANICAL PROPERTIES OF COPPER FOIL

		a*)	***b*)***
Tensile Strength	[MPa]	647	666
Yield Strength	[MPa]	-	-
Elongation	[%]	1.9	3.04

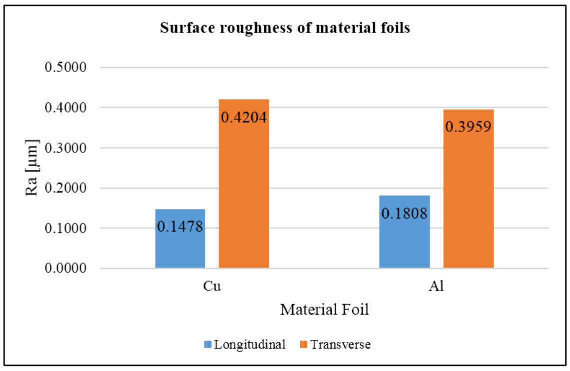


Figure 3. Material foils surface roughness

D. Experimental Process Parameters

Micro-blanking tool was mounted at micro-forming machine (Fig. 4). With the clearance between punch and die is 0.033 mm. To represent a sufficient range in punch velocities, it was determined that the blanking process conducted in 0.5 mm/s and 5 mm/s punch velocities. The process was held without any lubrication.

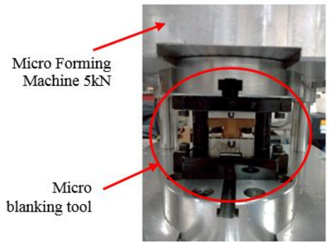


Figure 4. Mounted micro-blanking tool

The quality of the micro-blanking part is determined by the shear edge proportion (Fig. 5). A proportion of shear edge is occurred in micro blanking part same as in macro range, that are a zone of rollover (Rz), shear (Sz), fracture (Fz), and Burr (Bz).

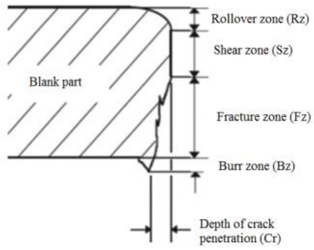


Figure 5. Shear edge [6]

The description of each portion are:

- Rollover zone (Rz): induced by plastic deformation
- Shear zone (Sz): smooth and shiny area formed during shearing stage
- Fracture/rupture zone (Fz): rough surface, occurs after the material cracks
- Burr zone (Bz): caused by plastic deformation
- Depth of crack penetration (Cr): fracture zone angle, clearance-depended
- Secondary shear: created if cracks do not run toward each other and material is sheared again

In this research, a blanking part was observed in scanning electron microscope Jeol JSM-6510LA to obtain the shear edge occurrence.

E. Results and Discussion

To quantify the shear edge quality, the proportion of the shear zones were observed. Table VII and Table VIII show the shear edge of micro-blanked part for aluminum and copper, respectively. Each material conducted in longitudinal and transverse rolling direction. There were some feature differences of shear edge proportion when different punch velocity was applied. Table IX and Table X show the ratio of each portion to the material thickness for aluminum and copper blanked-part.

TABLE VII. THE SHEAR EDGE OF ALUMINUM BLANKING-PART

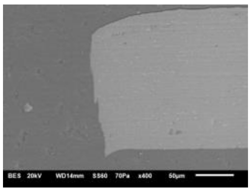
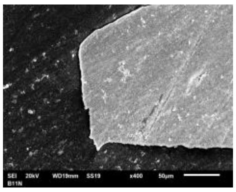
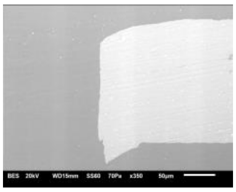
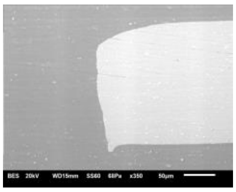
	Longitudinal	Transverse
v = 0.5 mm/s		
v = 5 mm/s		

TABLE VIII. THE SHEAR EDGE OF COPPER BLANKING-PART

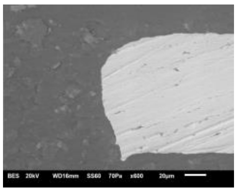
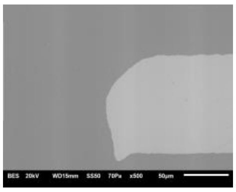
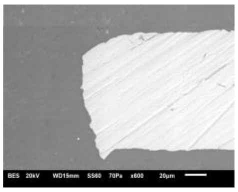
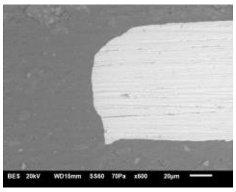
	Longitudinal	Transverse
v = 0.5 mm/s		
v = 5 mm/s		

TABLE IX. SHEAR EDGE PORTION OF ALUMINUM BLANKING PART

longitudinal rolling direction					
v	**Rz/t**	**Sz/t**	**Fz/t**	**Bz/t**	**Cr/t**
0.5mm/s	0.18	0.09	0.73	0.02	0.19
5mm/s	0.20	0.36	0.44	0.08	0.13
transverse rolling direction					
v	**Rz/t**	**Sz/t**	**Fz/t**	**Bz/t**	**Cr/t**
0.5mm/s	0.31	0.21	0.52	0.07	0.16
5mm/s	0.14	0.41	0.31	0.02	0.12

TABLE X. SHEAR EDGE PORTION OF COPPER BLANKING PART

longitudinal rolling direction					
V	**Rz/t**	**Sz/t**	**Fz/t**	**Bz/t**	**Cr/t**
0.5mm/s	0.28	0.33	0.39	0.06	0.19
5mm/s	0.21	0.36	0.43	0.08	0.20
transverse rolling direction					
v	**Rz/t**	**Sz/t**	**Fz/t**	**Bz/t**	**Cr/t**
0.5mm/s	0.45	0.09	0.30	0.05	0.09
5mm/s	0.30	0.33	0.38	0.04	0.13

Fig. 6 to 10 show the ratio of the shear edge proportion, relating to the punch velocity and the material rolling direction. The letter L and T signify a longitudinal and transverse orientation, respectively. In this study, a better quality of blanking part was determined by the larger shear zone portion and the smaller portion of the rest shear edge segments.

The results showed that the punch velocity influenced the decreasing of rollover, especially in copper foil (Fig. 6). The decreasing in transverse direction was bigger than in longitudinal one. While, in aluminum blanking-part, the decreasing of the rollover occurred only in transverse direction.

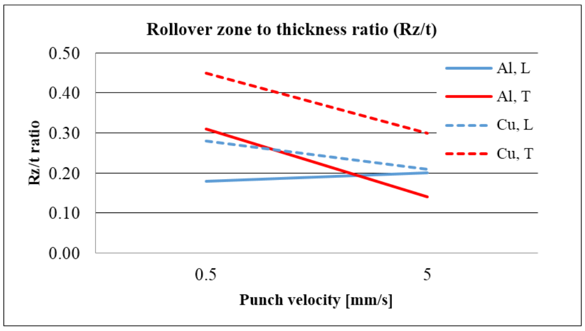


Figure 6. Ratio of Rz/t to the v1 and v2

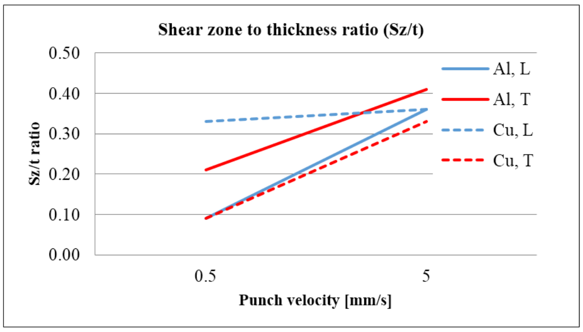


Figure 7. Ratio of Sz/t to the v1 and v2

Furthermore, the shear zones increased with the increasing of punch velocity for both aluminum and copper foil (Fig. 7). The shear zone in longitudinal was bigger than in transverse direction for aluminum part, while for copper, the shear zone was bigger in longitudinal direction. However, for copper material, the increasing of the shear zone was bigger in transverse rather than in longitudinal direction.

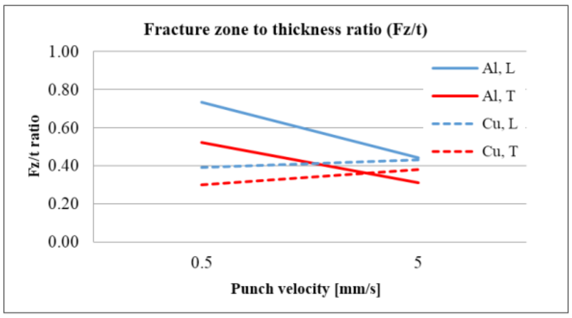


Figure 8. Ratio of Fz/t to the v1 and v2

An opposite result for aluminum and copper materials were showed in fracture zone and depth of crack penetration occurrence. With the increasing of punch velocity, the fracture zone and crack penetration of aluminum parts decreased. Meanwhile, the fracture and crack penetration portions increased for copper one (Fig. 8 and 10). In other hand, the fracture zones for both materials were smaller in transverse than longitudinal direction.

Grűnbaum *et al*. [6] stated that the burr height was not influenced by the punch velocity. However, Fig. 9 shows the decreasing of the burr zones occurred in transverse direction for both material, even though the burr zones increased in longitudinal one.

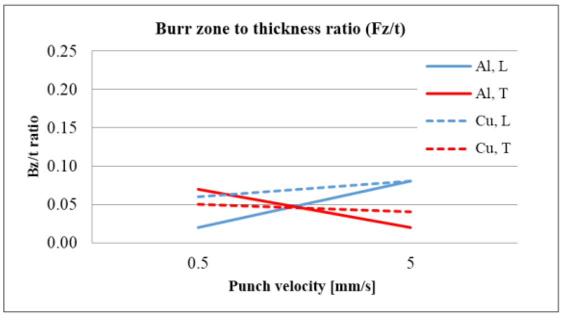


Figure 9. Ratio of Bz/t to the v1 and v2

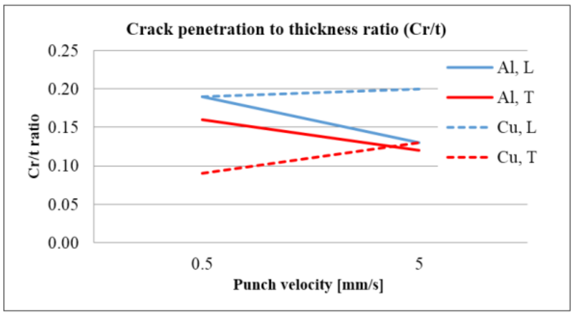


Figure 10. Ratio of Cr/t to the v1 and v2

The results showed that the determined process parameters could improve the shear zone portion for both materials, while the decreasing of fracture zone and crack penetration for copper foils were not obtained.

III. Conclusion

Micro-blanking part quality was strongly influenced by the die clearance. The larger die clearance, a greater irregularities of shear edge occurred. This research investigated about the influence of a punch velocity to the shear edge distribution. It is found that the proportion of shear edge in micro blanking part indicated the differences when punch velocity variation was applied.

For aluminum material, the shear zones increased for both longitudinal and transverse direction. The fracture zone and crack penetration decreased with the higher punch velocity. A good tendency in rollover and burr decreasing were showed in transverse direction. Similarly with the copper material, the shear zone also increased and the rollover zone decreased with a higher punch velocity. However, the fracture zone and the crack penetration slightly increased when the higher punch velocity was applied.

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Aida Mahmudah born in Bandung on March 24, 1978. She earned diploma degree in Manufacturing Design Engineering Department, Politeknik Manufaktur Bandung, Indonesia in 1999. She completed her bachelor and master degree in Mechanical Engineering Department, Universitas Indonesia, Indonesia in 2005 and 2013. Now, she in doctoral program in the same department. Her research interest is sheet metal forming technology. A challenge in micro level make her curious and strongly desire to contribute in micro forming technology development.

Gandjar Kiswanto born in Pontianak on April 20, 1972. He earned bachelor degree in Mechanical Engineering University of Indonesia in 1995. He completed his master and doctoral education of Production Engineering, Machine Design, Automation fields in the Department Werktuigkunde in 1998 and KU. Leuven in 2003. He is an Associate Professor of Mechanical Engineering at Universitas Indonesia, Depok, Indonesia. His research interest include machining, CAD/CAM system, micro machining and prototyping, and micro sheet metal forming.

His teaching career began in 1995. Until now, he is still actively teaching at the Department of Mechanical Engineering. Some of the courses he taught include Mechatronics, Automation and Robotics, Machine Vision Systems, CAD / CAM, and Basic Computer. Apart from being a lecturer, he also served as Head of Laboratory of Manufacturing Technology and Automation DTM UI. In the structure of the department, He served as Secretary of the Department and Head of Design, Manufacturing and Automation Sciences in Department of Mechanical Engineering. He also became a matter of Admission Test for bachelor and master program in University of Indonesia.

Dr. Ir. Gandjar Kiswanto, MEng. is also actively writing scientific publications. Some of his scientific publications are produced, i.e. An analytical method for obtaining cutter workpiece engagement during a semi-finish in five-axis milling, Analytical Method for Obtaining Cut Geometry of Helical Toroidal Cutter during Semi-Finish in 5-Axis Milling, Enhancement of 5-Axis Micromilling Visibility Through Visualization, Simulation, and Video Streaming in a Faceted-Based CAM-System

Dedi Priadi born in Jakarta on October 17, 1959, completed his bachelor in the Department of Metallurgy and Material Department, Universitas Indonesia in 1986, a master's degree in 1990 and his PhD in 1993 from the Ecole Nasionale Superiuer des Mines de Paris France. Field of expertise is Changing the Shape Material (Material Forming) as well as an interest in research in the field of Composite Materials, Structure and Rheology. His teaching experiences began at 1987. Now, he is a full professor at Universitas Indonesia. Apart from being a lecturer, he also served as Head of Metallurgical Mechanic Laboratory in 2008, five years as Vice-Dean of Education until 2013, and became a Dean of Engineering Faculty until now.

Prof. Dr. Ir. Dedi Priadi, DEA is still writing scientific publications. Some of his publications are Developing a Strength Analytical Method of Thin-Wall Steel SHS Beam by Combine Theory of Plastic Mechanisms and Non-Linear Elastic, Application of Hoop Stress Limit State and Predicted Corrosion Rate in Underground Gas Transmission Pipeline Inspection Plan, Effect of Coconut Fibers Addition to Early Age Unfired Soil Lime Bricks Strength.