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Finite Element Analysis of Coil-less Electromagnetic Forming on Prominent Industrial Materials

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ABSTRACT: Sheet metal forming is a contact metal forming process that uses an external force for material deformation whereas the electromagnetic forming process is one of the variants of forming techniques which is contactless metal forming technology. Since it can deform both conductive and non-conductive materials. Despite electromagnetic forming's distinctive deformation characteristics and forming quality, the method is still not widely used in the mainstream fabrication of industrial products. This is a result of electromagnetic forming's limitations in terms of adaptability in the manufacturing of custom-specific parts. Non-uniform electromagnetic force and non-uniform forming are obtained in traditional electromagnetic forming and it causes improper forming surfaces. Coil life is affected due to thermal and mechanical loads applied to the coil while forming. To overcome these limitations coil-less electromagnetic forming method is proposed and it is a contactless metal forming technology that uses electromagnetic force to deform materials for both conductive and non-conductive materials. The aim of the article is to design the coil-less EMF process and to obtain the deformation and formability characteristics of sheet metals for various materials through finite element analysis. The deformation of various sheet materials was studied and the results of the deformation were compared. Coil-less EMF process has applications in a number of industries, including automotive, aerospace, sheet metal manufacturing, electrical sector and bio-medical. As a result, a new forming process was designed and analyzed using Finite Element Simulation. The coil-less electromagnetic forming process results are validated for the different materials.

KEYWORDS: Metal forming, Magnetic pulse, Coil-less Electromagnetic Forming, Deformation, Finite Element Analysis, Sheet metal forming, Material deformation, Conductive and non-conductive materials.

I. INTRODUCTION

1.1 Overview of electromagnetic forming

Sheet metal forming is a contact metal forming process which uses an external force for material deformation. The work piece material is shaped without adding or removing of the materials, it undergoes plastically permanent deformation. This manufacturing process shapes the materials below their recrystallization temperature. Sheet metal forming has various techniques such as bending, drawing, stamping, shearing, bulging, flanging, and stretching. This process has no materials waste and a suitable grain flow compared to other processes. Sheet metal forming has some limitations such as, it needs a higher force to deform the materials, due to the air gap between the work piece and die will decrease the precision of the work piece, the thickness variation of the material, and tool contact will affect the surface of the material. These limitations create a research gap and help to identify the new process called the electromagnetic forming process. Electromagnetic forming is developed to obtain the shapes of sheet metals which could not be formed by the conventional sheet metal forming process. The Electromagnetic field creates the force toward the work piece to form the desired shape. Electromagnetic forming has a high strain rate and has the potential to form a material with high formability. Electromagnetic forming can be combined with two or more processes to form materials with different operations. In the late 1920s, many types of research were conducted with electromagnetic techniques to deform materials; it is mostly a manual forming process. Electromagnetic forming is implemented in the year 1964 in the General Motors industry (GM). General Motors uses the electromagnetic forming technique for

joining the automobile parts. The first industrial component manufactured using the EMF process is shrinking the retainer rings on neoprene boots and it is shown in Figure.1. This electromagnetic forming machine is built by General Atomics - research and technology development corporation. Some uniqueness of electromagnetic forming is, it is a contact-less forming, so there is no tool wear, when compared to the conventional process the formability is increased, wrinkling can be reduced, electromagnetic joining can be performed for dissimilar materials such as metals, glass, plastic and composites [1].



Fig.1 The first industrial component manufactured using the electromagnetic forming process.

1.2 Evolution of electromagnetic forming

In early times electromagnetic forming is mostly used in the research and development institutions because it is not familiar among the industries. In contrast to other forming processes, this one seems to be more expensive. After the gradual development of electromagnetic forming, manufacturing industries started using it for production. This is the major reason for the evolution of electromagnetic forming. The non-uniform distribution of magnetic field, coil effect on the material surface, and improper forming are some limitations of conventional forming, to overcome from these problems an advanced electromagnetic forming is needed. Multi-operation components must undergo various processes separately, which leads to an increase in production cost and time, and some materials are difficult to form with high thickness, to solve these issues a hybrid electromagnetic forming process is needed it is a combination of two or more processes of forming. Despite electromagnetic forming's distinctive deformation characteristics and forming quality, the method is still not widely used in mainstream fabrication of industrial products. This is a result of electromagnetic forming's limitations in terms of adaptability in the manufacturing of custom-specific parts. Even though electromagnetic forming is a rapid forming process and also has a high formability when compared to conventional processes but it has some challenges such as improper distribution of magnetic field. Coil life is affected due to thermal and mechanical loads applied to the coil while forming. To overcome these limitations coil-less electromagnetic forming method is proposed. Figure.2 represents the (a) Electromagnetic forming process, (b) Circuit diagram of electromagnetic forming.

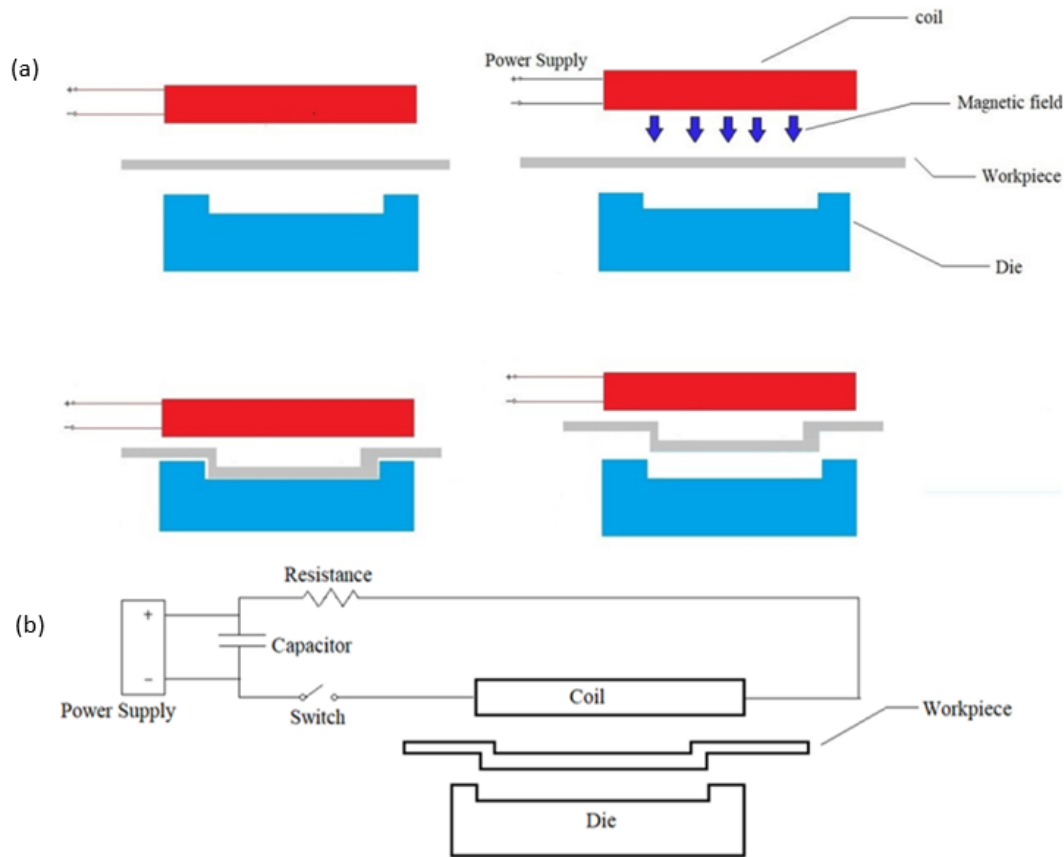


Fig.2 (a) Electromagnetic forming process, (b) Circuit diagram of electromagnetic forming.

II. LITERATURE REVIEW

Xiong et al. (2019) proposed a method called dual coil electromagnetic forming. Instead of being inside the tube, the two separate driving coils were placed at the end. The results of theoretical analysis and simulations hold great promise for the development of electromagnetic forming systems and the expansion of their scope for use in tube flanging. Quanliang et al. (2021) developed a coil-less electromagnetic sheet metal forming system. Understanding the coil-less forming process and advancing electromagnetic forming can both benefit from the numerical and experimental results. Trzepieciniski. (2020) did a study on recent development in electromagnetic forming and computerized incremental sheet forming processes. Explains the variants of electromagnetic forming and their future prospects. Liu et al. (2018) The mechanisms of reduced rebound effect in indirect EMF are revealed, as well as the influence factors of fittability in indirect EMF. Finite element models of direct EMF and indirect EMF with an elastic medium are established. The best fittability is achieved when the driver plate's thickness and skin depth are equal. Qiu et al. (2012) suggest evaluating capacitance in electromagnetic (EMF) forming. The capacitance of EMF is analysed using a finite element analysis, and its coefficient and designs were created. The driving coil's increased strength improves the process's capabilities. Mohammed et al. (2021) conducted research on the harness of an aluminium alloy using a single-point incremental forming process. By adjusting the parameters, he examined the process, and the findings revealed that the tool speed has an impact on the hardness of the alloy. Xia et al. (2022) suggested that the electromagnetic forming process might benefit from a slight vibration. A common drawback in the forming of sheet metal is the spring back effect, which is reduced by this process. Qiu et al. (2020) present a new method to overcome the Uneven axial deformation issue based on employing a magnetic field shaper. From the results, the maximum uniform deformation area is increased than without a field shaper.. Feng et al. (2022) A new electromagnetic forming method named direct pulse current EMF for the material Ti-6Al-4 V. The results show the fine replication of the corrugation die and no oxidation occurrence of titanium alloy specimen.

Thus, the Literature Review papers resulting in the Coil-less Electromagnetic forming process are reviewed and the research gap, problem identification and Objectives are presented in the next chapters.

III. PROBLEM IDENTIFICATION

Sheet metal forming is a familiar and prominent process in sheet metal but it has some limitations such as tool wear, forming quality, and material failure due to high load. To rectify these limitations, electromagnetic forming process is developed. Despite electromagnetic forming's distinctive deformation characteristics and forming quality, the method is still not widely used in the mainstream fabrication of industrial products. This is a result of electromagnetic forming's limitations in terms of adaptability in the manufacturing specific parts. Even though electromagnetic forming is a rapid forming process but it has some challenges such as improper distribution of magnetic field and coil life. Problem identification for electromagnetic forming is listed below,

1. Electromagnetic forming is a relatively complex process for designing and manufacturing coils.
2. Coil life is limited due to both mechanical and thermal loads in the conventional forming process.
3. Using standard shapes like spiral, round and flat in the coil will create non-uniform force in the work piece during the process which affects the forming quality.
4. To solve these problems Coil-less Electromagnetic forming process is proposed.
5. The process of Coil-less electromagnetic forming is shown in Figure.3. In contrast to conventional mechanical forming techniques, which rely on physical pressure, electromagnetic forming uses a strong magnetic field to produce forces that cause deformation.

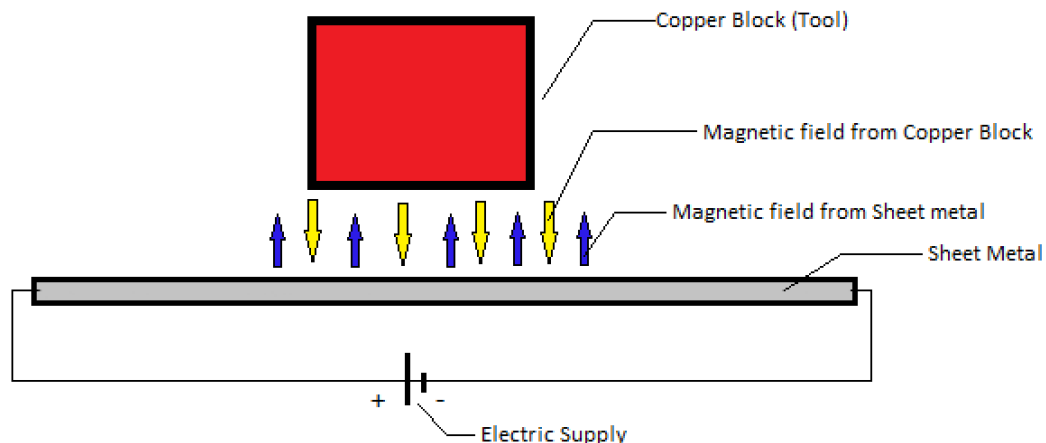


Fig.3 Coil-less Electromagnetic Forming Process.

IV. METHODOLOGY

The process flow chart of the Finite element analysis of electromagnetic forming is shown in Figure.4 and the designing is done using modeling software. The 3D models of tool, work piece, and the dies were designed separately and assembled. Finite element analysis was done using finite element analysis software. This is used for a wide range of applications, including structural analysis, fluid dynamics and electromagnetic simulation. The designed part is imported to FEA software and analyzed the electromagnetic simulation of coil-less electromagnetic forming. The 3-Dimensional model of coil-less electromagnetic forming is shown in Figures 5 and 6. The results of various materials were compared with each other and the height and lowest deformation materials were validated. The copper block used in the simulation is 40 length, 40mm height and has a width of 120 mm this is chosen by referring to some journal papers related to electromagnetic forming. The thickness of sheet metal is 1mm. For sheet metal forming a thickness of 1mm and length of 150 mm is suitable for best-forming quality. Die is also designed to shape the sheet metal to its desired shape. The copper block (tool) and die can be varied according to the shapes needed.

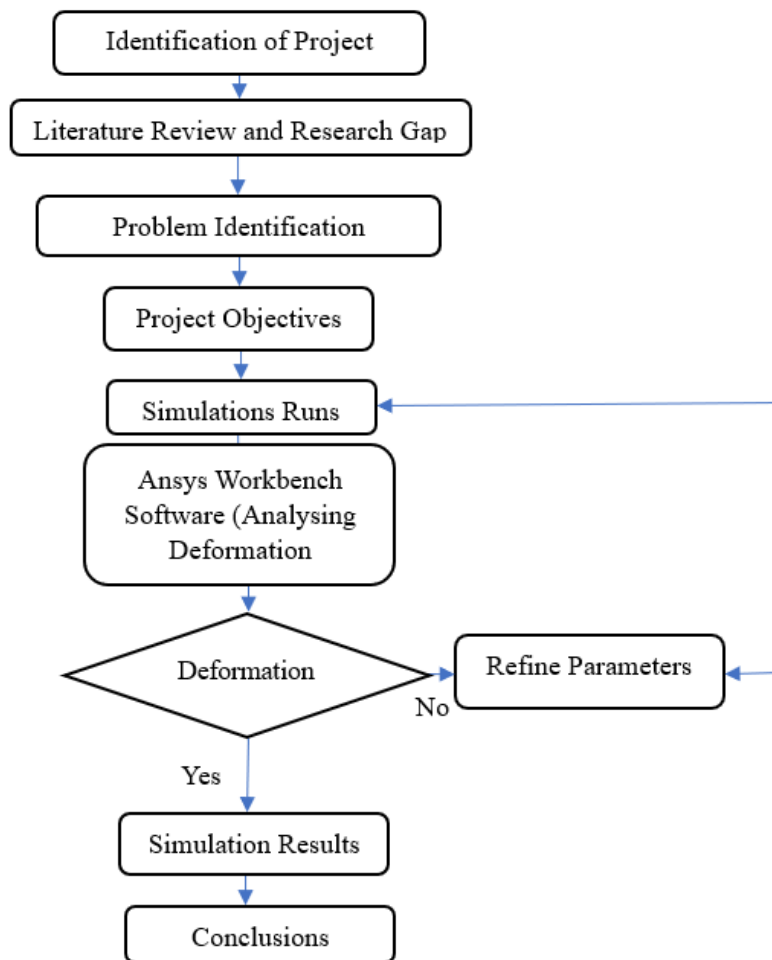


Fig.4 Methodology flow chart of Finite Element Analysis of Coil-less Electromagnetic Forming

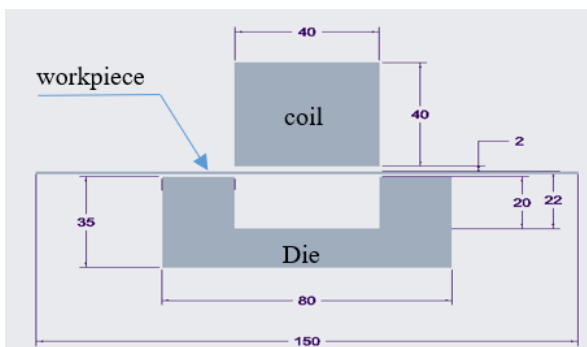


Fig.5 “3D model of Coil-less Electromagnetic forming”.

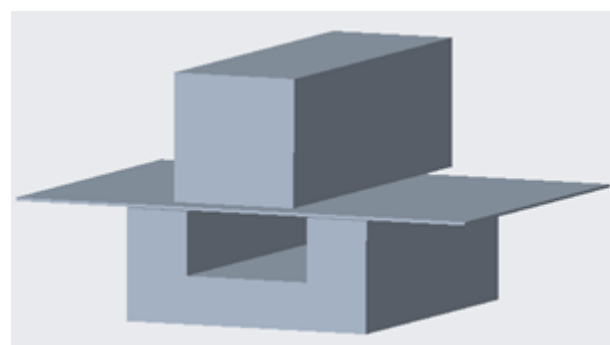


Fig.6 Isometric view of Coil-less Electromagnetic forming.

V. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a numerical method used to solve engineering problems by dividing a complex physical system into smaller, more manageable parts called finite elements. It is widely used in various fields of engineering, including structural analysis, heat transfer, fluid dynamics, and electromagnetics. By using FEA software these problems can be solved easily. By assuming that the displacement, temperature, velocity, the behaviour of the



system can be roughly predicted. The number of elements and mesh refinement can be increased to increase the accuracy of the solution. It helps with structure design and optimization, material performance assessment, fluid or thermal flow simulation, and various physical phenomenon simulations. For deformation analysis “Explicit dynamics” system analysis has been selected. The process flow of the finite element analysis is shown in Figure.7. The Outline pane contains a tree with all the settings you add to the model. The Details pane will provide options for each of these settings that are given to the model for the analysis.



Fig.7 Process flow of Finite Element Analysis of Coil-less EMF.

VI. RESULTS AND DISCUSSION

The results of the simulations such as total deformation, and equivalent stress shown in Figure.8 for Aluminium-AA1100, Figure.9 is for stainless steel-SS316, Figure.10 is for structural steel and Figure.11 is for Titanium alloy respectively. The influencing Parameters and deformation characteristics of Coil-less electromagnetic forming are shown in Table 1, and Table 2 represents the comparison of forming methods and forming heights with other articles.

Table 1 Parameters and deformation characteristics of Coil-less Electromagnetic Forming

SNo	Material Name	Coil Type	Deformation (mm)	Velocity (mm/s)	Stress (MPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Young’s Modulus (MPa)	Poisson’s Ratio	Elongation (%)
1	AA1100	Copper Block	14.373	590000	38558	89.7	264	80000	0.33	12
2	SS 316	Copper Block	7.356	900000	32429	586	207	193000	0.31	40
3	A36	Copper Block	15.848	560000	11700	550	240	190000	0.30	23
4	Ti-6Al-4V	Copper Block	3.53	475500	14496	1070	930	96000	0.36	14

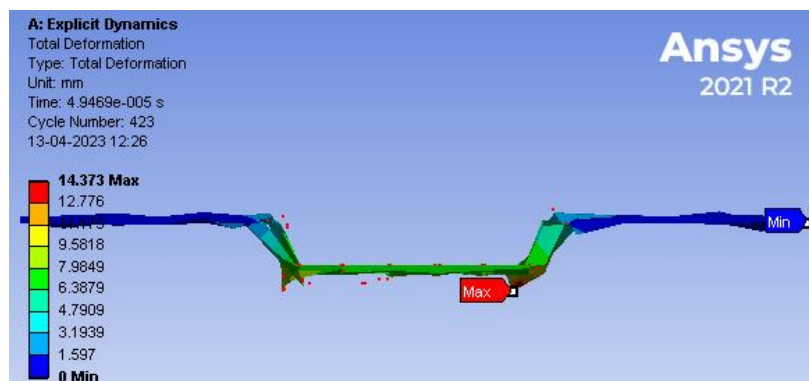


Fig.8 Total Deformation of sheet metal Aluminium (AA1100).

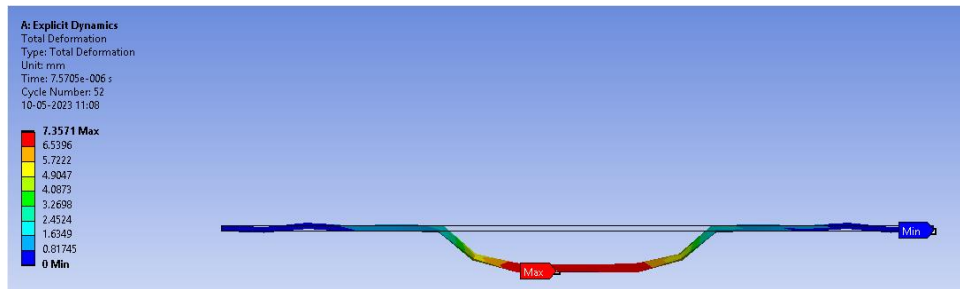


Fig.9 Total Deformation of sheet metal Stainless Steel (SS 316).

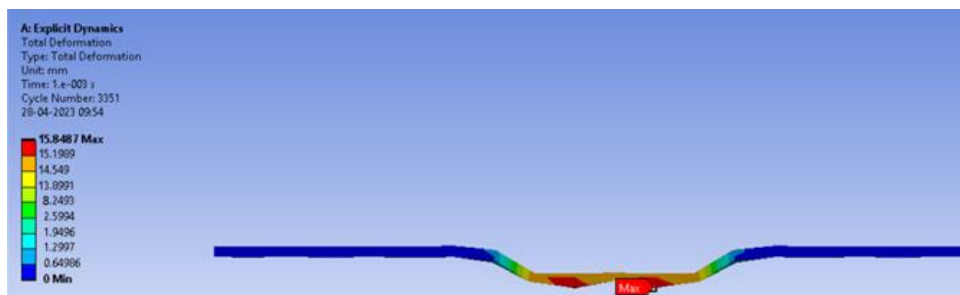


Fig.10 Total Deformation of sheet metal of Structural Steel (A36)

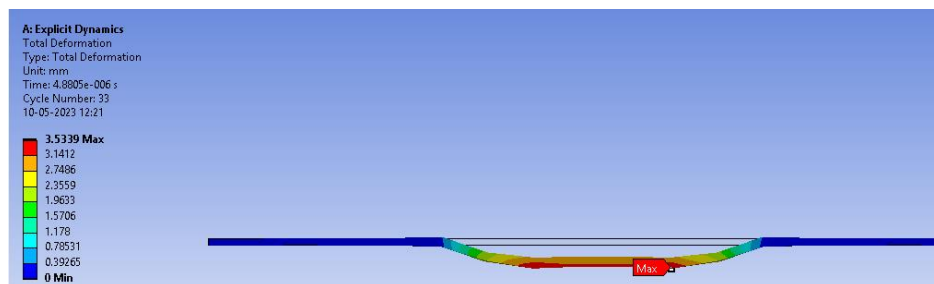


Fig.11 Total Deformation of sheet metal Titanium Alloy (Ti-6Al-4V)

Table 2 Comparison of forming methods and forming heights with other articles

S.No	Forming Methods	Deformation (Mm)	Article Names	References
1	Coil-less EMF	3.5 to 15	Finite Element Analysis of Electromagnetic Forming	-
2	Coil-less EMF	2.25 to 2.41	Coil-less EMF process with uniform-pressure	[2]
3	Direct EMF	5 to 16	Direct pulse current EMF, a novel electromagnetic forming for aluminium alloy sheet	[3]
4	Direct & Indirect EMF	10	Comparative Research on the Rebound Effect in Direct EMF and Indirect EMF	[4]
5	Two-stem EMF	16.24 to 16.99	Two-step EMF: A new forming approach to local features of large-size sheet metal parts	[5]

VII. APPLICATIONS

The applications of coil-less electromagnetic forming in terms of prominent industrial materials are listed below,

1. Different shapes can be formed by coil-less electromagnetic forming from micro to macro parts and hallow and non-circular shapes can be formed.
2. Coil-less EMF is used in sheet metal welding, and bulging in automobile industries.
3. Bending of tin and tin plates, tube shrinking and compression in liquid and pipe industries.
4. Micro clamps, pins, and plates in electronic applications.
5. Bending of tubes into complex shapes.
6. Shearing, piercing, and riveting can also be manufactured by coil-less Electromagnetic forming.

VIII. CONCLUSION

The Coil-less electromagnetic forming process is simulated and their results were obtained. The simulation deformation of the desired shape has been obtained using the Explicit Dynamics method in FEA software. By varying the parameters such as work piece thickness, velocity can make a change in forming height. As a result, a new forming tool and the forming process have been designed and analysed and the results of deformation and equivalent stress are observed for the different materials such as aluminium, stainless steel, structural steel, and titanium alloy. From the obtained results the Structural Steel (A36) has the highest deformation of 15.8 mm, and the lowest deformation is for Titanium alloy (Ti-6Al-4V) of 3.5mm and by varying the parameters such as velocity, standoff distance, material type, work piece thickness can change the deformation of the materials.

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