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FORMING WITH HYBRID TECHNOLOGY - INTEGRATION OF ELECTROMAGNETIC PROCESS INTO CONVENTIONAL FORMING

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ABSTRACT

In recent years automotive industry has a trend to minimize weight of their products by introduction of various new materials. Steel is more and more reduced and instead aluminum alloys are used. Aluminum alloys have almost three times smaller density than steel but have lover yield points. At higher deformations during processing they become less ductile and failures could appear. These failures can be reduced or even eliminated by using high-speed forming such is electromagnetic forming.

Electromagnetic forming (EMF) is non-contact high strain-rate forming process using magnetic force for shaping or joining sheet metal. It is precise and rapid technique without heat effects or tool marks, associated with conventional forming. Integration of EMF into conventional sheet metal forming technology has been developed for forming operations of hard formability materials with high electrical conductivity, such as aluminum, copper or brass. Its purpose is to avoid failures in conventional processes such as deep drawing, stamping, banding, piercing, or sheet metal stretching, when it is cold formed with high degrees of deformation.

Paper presents studies of hybrid sheet metal forming processes where combination of EMF and conventional forming technologies offers reliable production of complex aluminum parts. Authors are aware to implement such hybrid processes into Slovene metal processing industry and their idea was accepted by Slovene research community by supporting an adequate research project.

Keywords: *sheet metal forming, high-strain rate, aluminium alloys, electromagnetic, multistage, hybrid processes.*

1 INTRODUCTION

Idea of electromagnetic forming as sheet metal forming process firstly appears in middle 1950's. In industry EMF application was first introduced by General Motors in 1964 for banding of neoprene boots onto automotive ball joints [10]. EMF technologies are popular in the aerospace and automotive industries due to theirs advantages in enabling the fabrication of many complex geometry parts and in enhancing the formability of low ductility materials such are aluminum and brass. Aluminum is the ideal material for replacing the steel in cars, airplanes or any product which needs to be lightened. It is expected to form very complex shapes with small radius, which demand high formability. Materials with small ductility such as aluminum can achieve higher formability with high forming speeds. Electromagnetic forming belongs into one group of high-speed forming technologies.

Theoretically EMF can form any kind of material that is conductive. Best materials for EM forming are materials with high conductivity, such as brass, copper, low-carbon steel and aluminum. Process needs a lot more energy for workpieces with low conductivity therefore some of them are coated with thin layer of high conductive material to successfully form workpiece into desired geometry.

Electromagnetic forces are used at EMF technique to deform metallic workpieces at high speeds. In this process, a transient electric current is induced in a coil using a capacitor bank and high-speed switches. This current induces a magnetic field that penetrates the nearby conductive workpiece where an eddy current is generated. The magnetic field, together with the eddy current, induces Lorentz forces that drive the deformation of the workpiece. In an EMF process, the material of workpiece can achieve very high accelerations and decelerations. The dynamics of this event, including die impact, enhance the formability of the workpiece and reduce springback. The process has also some other advantages comparing with conventional forming techniques such as repeatability (because of its electric nature, energy input can be carefully adjusted), non-contact (no lubrication needed and no tool marks to worry about) and an accuracy. Thus, EMF is expected to help overcome some formability barriers that prevent more widespread use of materials such as aluminum in lightweight structural applications [6,7].

Almost all of EMF operations can be preformed in one step so it can reduce number of steps in multistage forming which means that it can reduce number of forming tools used and time spent for whole process. Process does not require any infrastructure; most space is used by capacitors. Coils can be simple and can be mounted in conventional forming tool. They can be easily replaced with different shape of coil for different geometry of a product. Process does not need lubrication and after forming part does not need surface cleaning or grinding of edges.

In these article possibilities of integration EMF into different multistage forming of aluminum and its alloys will be described. There is a chance that with the process combination reduction in forming time, number of forming processes and used energy for manufacturing of end product can be achieved.

2 MULTISTAGE FORMING

Multistage sheet metal forming of part is combined from different forming techniques such as deep drawing, blanking, drawing, sizing, trimming, piercing, flanging, or from multi stage forming technique of one forming process such as first deep drawing, second deep drawing, etc. On Figure 1 multistage forming is shown. It consists from several different forming processes and it is combination of deep drawing, trimming and piercing.

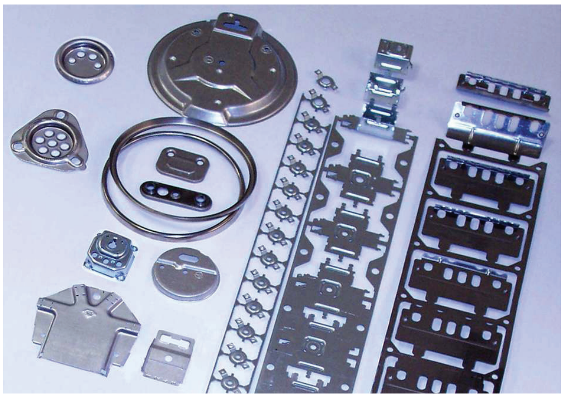


Figure 1 - Products made from multistage forming (source: ETA d.o.o. Cerkno)

Number of forming operations and their sequence defines possibility of manufacturing workpiece effectively, quality and in fixed time limit. Changes in one step of multistage forming affect on whole system and so quality of end product can be diminish. More steps of multistage forming, more presses and tools are needed, which will increase starting costs and reduce productivity of the forming process [2].
Knowing particular forming technology and sequence of these operations in multistage forming starting thickness of sheet metal can be determinated from end thickness, which is defined by client. When optimal choice of technologies is selected part can be manufactured with high precision, while selection of wrong technologies, wrong starting thickness or even wrong sequence of technologies can effect on part in such manner. Optimal position of the workpiece on the sheet metal also perform significant role in multistage forming, which is important for maximize use of applied material.
To assure the best quality of product, the number of forming steps must be low as possible. The sequence of multistage forming is mostly still depended upon experience of engineer; however construction of forming steps in multistage forming is durable, difficult and exact.

2.1 Deformation paths in multistage forming

The path of deformation at multistage forming is not consistent (relation between deformation are not constant). So the sequence of forming techniques has big influence on forming ability of used material. Forming limit diagrams are the best way to show that phenomenon (Figure 2). Forming limit diagram shows to what limit it can deform sheet metal with different forming techniques without a local contraction.
The Figure 2 shows that if at first material is stretched with biaxial forming with booth positive main strain and than with unaxial forming technique (path: 0 - A - B), the curve of forming limit diagram is very low (curve b). With such sequence of forming processes it can be achieve much lower deformations of material than with single-stage forming (path: 0 - E). However, if material is formed first with unaxial forming and than with biaxial forming technique (path: 0 - C - D) the curve of forming limit diagram is higher (curve c) than curve obtained with single-stage forming (curve a). With that knowledge the formability of material and its deformations can be increased significantly [3].

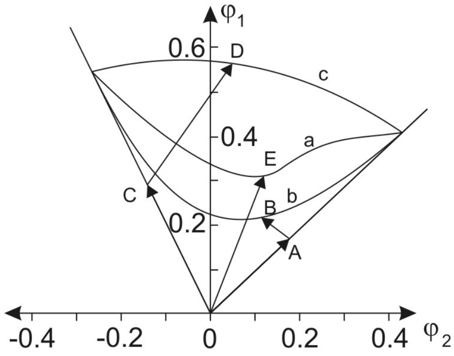


Figure 2 - Forming limit diagram for three different sequence of sheet metal forming [3]

3 ELECTROMAGNETIC FORMING

Generally system of electromagnetic forming consists of capacitor, coil and high conductive workpiece. Capacitor is connected to the coil which is close to formed workpiece. When the circuit is closed stored electrical energy from capacitor is released and provide high electrical current to the coil. This current causes temporary magnetic field around the coil and induce eddy currents on the surface of the workpiece.
Combination of eddy currents and magnetic field than generate enough force that can deform workpiece into desired product. Acceleration of sheet metal is up to 100 m/s in only 0,1 ms and achieved pressure is up to 300 MPa. This reduce springback and increases formability of material which is shown on Figure 3. Material, formed with high-speed forming, such as EMF, reach higher deformations till local contraction at the same thickness of sheet metal. When forming process is done, there are no effects connected with high temperatures or tool marks visible on workpiece which are significant for other conventional forming techniques, since the coil never touches the workpiece [9].

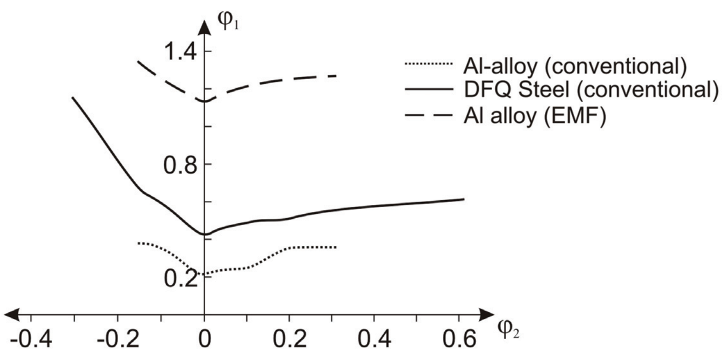
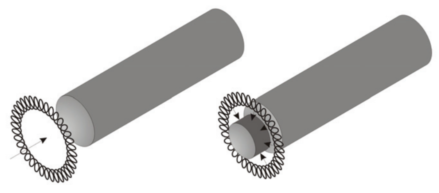
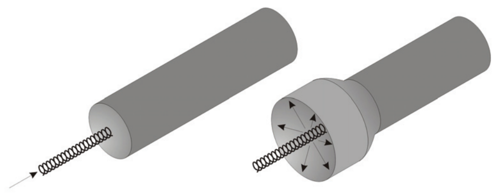


Figure 3 - Increased formability of aluminium alloy [8]

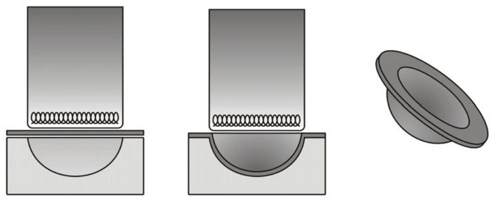
Technology is mostly used for one-stage forming, such as compression or expansion of tube workpiece (for joining axis or supporting beams), flat forming, riveting or in combination with conventional forming methods as for instance stamping and deep-drawing. Figure 4 shows three different processes of the electromagnetic forming which are mostly used in industry.



a) Electromagnetic compression



b) Electromagnetic expansion



c) Electromagnetic flat forming

Figure 4 - Three different EMF processes [1]

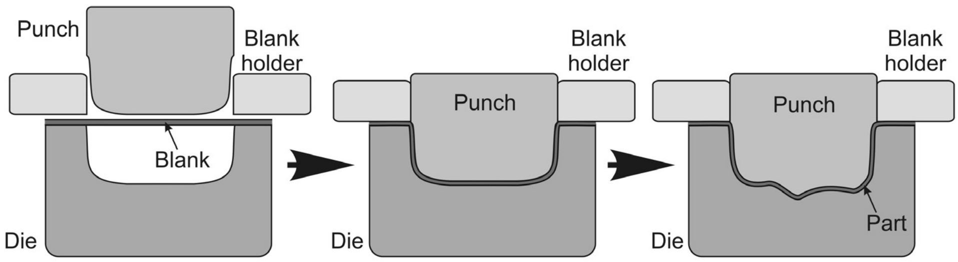
EMF process can be carried out with high precision and repeatability, which give this technology advantage from conventional forming in forming of aluminum. Best materials applied for EMF technology are materials with high electrical conductivity, such as copper, aluminum, low-carbon steel, bras and molybdenum. Materials with low electrical conductivity, such as stainless steel can be formed with very high electrical energy, which is not profitable, or with intermediate, highly conductive conductor. Also the technique can be applied to metallic materials, which are coated with non-metallic layer, since the magnetic field can passes trough non-conductive materials. Magnetic field behaves like compressed air, producing a constant pressure and is generally independent on the size of the gap between the workpiece and forming coil [1].

4 HYBRID TECHNOLOGY

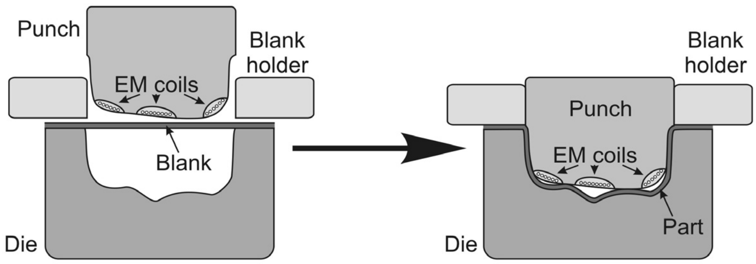
Multistage forming has also problems with its design, since for each step forming tools must be manufactured. Particular step in multistage deep drawing a punch and a die must be made to form workpiece into a finite product.

As said, with EMF technology formability of metals can be improved. As it is known, aluminium has very small formability witch can increased with high speed forming technique. So combination of conventional forming technique and EMF can be mostly used for forming aluminium sheet metal.

Hybrid technology of EMF and conventional forming techniques can be divided into two groups. First is incorporation EM coils into conventional tool and second is technique where preforming stage is made with conventional tools and finishing stage is made with EMF tools.



a.) Multistage deep drawing



b.) Integration EM process into conventional forming

Figure 5 - Comparison of multistage deep drawing and hybrid technology with incorporation of EM coils into conventional tool

With incorporation of EM coils into conventional tools the number of different tools can be reduced. Figure 5 shows comparison of multistage deep drawing and hybrid technology of deep drawing and EM forming processes. As can be seen the multistage deep drawing requires a large number of different punches and dies, which give us higher initial cost in setting up the system, while hybrid design reduce number of punches, as well as number of dies.
Technique where conventional forming is used to preform and EMF for finishig, parts are preformed to some optimum extent with conventional forming techniques, such are deep drawing, bending, stretching. Final stages, where deep pockets or sharp edges are needed, are made with single stroke EMF technique, for higher depth repeatedly, incremental stretching is applied [9].
Technologies like banding, piercing, riveting or stretching can be also preformed with EMF technology. All these technologies can be incorporated into multistage forming system and therefore there is no restriction to perform them with EM forming. This would reduce the time and costs of manufacturing of an end product.

5 INDUSTRIAL APPLICATION

This hybrid technology is already used in some industrial applications. Car industry is trying to replace steel for lighter materials for their bigger parts such as door panels or bonnet since they bring up a lot to weight of the vehicle. The best candidate for replacing is aluminium and its alloys.

Aluminium does not have large forming capabilities which are already shown on Figure 3, but through rapid forming technologies such as EMF an excellent forming of this material is possible. Figure 6 shows an example of the project in collaboration with industry on the Ohio State University, where EM forming of aluminium was successfully imparted in multistage process. This technology can achieve small radius and exact geometry of finite part. Figure 6(a) presents part before EM forming that has been preformed with conventional forming operation. The final form of the product can be seen on figure 6(b), which was completed using EM forming.

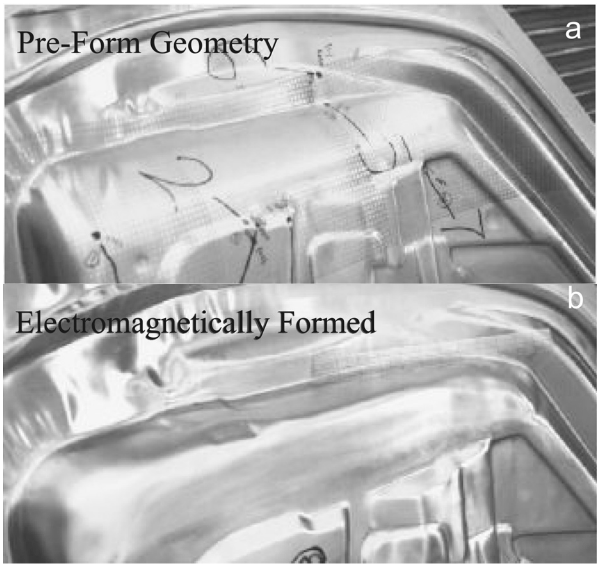


Figure 6: Example of pre-formed part (a) and formed to final shape using EM forming (b) [6]

6 CONCLUSION AND FUTURE WORK

Hybrid technology of EMF and conventional forming has been investigated for necessity of Slovenian industry. Different possibilities of mounting EMF into multistage conventional forming operations were suggested. Some of these combinations were already proven as good substitute for conventional forming of aluminium. Selecting proper parameters EM forming can be very precise technology which can be successfully built into multistage forming.
In the future the research work will be directed toward definition of FEM models in order to perform results in advance and real experimental work in order to increase energy efficiency of the process.

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HIBRIDNA TEHNOLOGIJA OBLIKOVANJA - INTEGRACIJA ELEKTROMAGNETNOG PROCESA U KONVENCIONALNO DEFORMISANJE

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REZIME

Poslednjih godina automobilska industrija je u trendu smanjivanja težine vozila upotrebnom novih materijala. Upotreba čelika se sve više smanjuje i njegovo mesto zauzima aluminijum. Legure aluminijuma imaju gotovo tri puta manju gustinu od čelika, ali i manji napon tečenja. Prilikom oblikovanja pri većim stepenima deformacije, smanjuje se duktilnost ovih legura tako da može doći do pojave grešaka-pukotina. Ove greške se mogu smanjiti ili u potpunosti izbeći upotrebom visoko-brzinskog elektromagnetnog deformisanja.

Elektromagnetno deformisanje (EMF) je postupak bez-kontaktnog oblikovanja delova sa velikim stepenima deformacije pomoću magnetnih sila. Ovaj postupak se pored oblikovanja može koristiti i za spajanje delova od lima. Osim što je precizna i produktivna ovu tehnologiju karakteriše i odsustvo zagrevanja radnog predmeta kao i prisustvo otiska alata karakterističnih za konvencionalno deformisanje. Integracija EMF sa konvencionalnim deformisanjem lima je razvijena za potrebe deformisanja teško deformabilnih materijala sa visokom električnom provodljivošću, kao što su aluminijum, bakar i mesing. Cilj ove tehnologije je da se izbegnu grešaka koje se javljaju kod konvencionalnih postupaka, kao što su duboko izvlačenje, razdvajanje, savijanje, probijanje i razvlačenje, prilikom hladnog deformisanja pri velikim deformacija.

Ovaj rad prikazuje istraživanje hibridne tehnologije deformisanja, gde kombinacija EMF i konvencionalno deformisanja obezbeđuje pouzdanu proizvodnju kompleksnih delova od aluminijuma. Autori su uvereni u mogućnosti implementacije ovog hibridnog procesa u slovenačku industriju obrade metala i njihova ideja je bila prihvaćena i podržana od strane slovenačkog društva za razvoj.

***Ključne reči**: deformisanje lima, visoke deformacije, legure aluminijuma, elektromagnetika, višestepeni, hibridni procesi.*