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THE EXPERIMENTAL AND NUMERICAL STUDY OF THE FORCES DURING THE INCREMENTAL FORMING OF TITANIUM SHEETS

Al Darabseh Amer Mohammad Farhan

Engineer Aircraft & Helicopter Engineering and Power Supply

amersamarah4@gmail.com

Markova Elena Vladimirovna,

Ph.D., associate professor

Department of " General science disciplines"

morozova319@yandex.ru

Denisova Tatyana Valentinovna,

Ph.D., associate professor

Department of "Economics, Management and Computer Science"

denisovaiatu@mail.ru

Institute of Aviation Technologies and Management,

Ulyanovsk State Technical University, Ulyanovsk, Russian

Abstract. Incremental forming is a rapid prototyping process that allows sheets to be formed without using forming tools, using a numerically controlled machine tool. A wide variety of shapes can be generated with this process.The objective of this work is to study through experimental tests and numerical simulations the behavior of ASTM grade 2 titanium during incremental point forming (SPIF). A Spinner MFG850 machining center from ISET in JENDOUBA coupled to a multi-component force sensor FN7325 was used for the forming of thin sheets by this process. As the diameter of the punch and its incremental movement are parameters having a direct effect on the forming force, tests with diameters of the punches dp varying between 10 and 15 mm and various paths made up of circular movements in

the horizontal plane have been carried out experimentally. Numerical simulation is carried out in large elastoplastic deformations with ABAQUS/explicit. Comparisons of the evolution of the forming force for different values of the diameter of the punch dp and of the displacement step Δzare carried out.

Keywords: incremental forming, titanium, finite elements, experimentation, instrumentation.

The incremental forming process is a sheet forming process, which locally and gradually deforms the sheet by embossing by moving a small punch whose path is controlled by a CNC machine. This process makes it possible to obtain pieces of various shapes, asymmetric or not. Good conformity of the final geometry of the part obtained is linked to the choice of several parameters such as the speed of advance and of rotation of the tool, the displacement increments, the diameter of the tool [1].

Titanium's properties, which are a combination of high strength, toughness, toughness, low density, and good corrosion resistance offered by various titanium alloys at low and high temperatures, allow for weight savings in space structures and other high-performance applications.

The atomic weight of titanium is 47.88. Titanium is lightweight, strong, resistant to corrosion and available in nature. Titanium and titanium alloys possess tensile strengths from 30,000 psi to 200,000 psi 210-1380 MPA, which is equivalent to the strength found in most steel alloys [2].

Titanium is a low-density element about 60% the density of iron in which alloying can be strengthened. Titanium is a non-magnetic metal and has good heat transfer properties [3]. Its coefficient of thermal expansion is less than that of steel and less than half of coefficient of thermal expansion of aluminum. One of titanium's beneficial properties is its high melting point of 3135 degrees Fahrenheit 1725 degrees Celsius. The melting point is about 400 ° F above the melting point of steel and about 2000 ° F above that of aluminum. Titanium can be passivated and thus exhibit a high degree of immunity to attack by most mineral acids and chlorides. Titanium is non-toxic and generally biocompatible with human tissue and bone.

Excellent resistance to corrosion and biocompatibility along with a strength that makes titanium and titanium alloys useful in biological, chemical, petrochemical, and marine environments [4]. Titanium is not a good conductor of electricity. If the electrical conductivity of copper is considered to be 100%, then titanium has a conductivity of 3.1%. It follows from this that titanium will not be used as a major factor in good conductors. For comparison, stainless steel has 3.5% conductivity and aluminum has 30% conductivity. Electrical resistance is the opposition to the flow of electrons. Since titanium is a weak conductor, it follows that it is the fair resistor [5].

The asymmetric incremental forming of AISF sheets can be divided into two forming modes depending on the number of contact points between the sheet and the tool. The most studied process and which is the subject of this work is the «SPIF: single point incremental forming» incremental forming. The principle of one-point incremental forming is shown in Figure 1. The blank placed on a die is fixed using a blank clamp. The hemispherically shaped punch rotated acts incrementally in directions defined by the path programmed on the CNC machine. The use of this process requires a good knowledge of the behavior of the material in order to avoid stringback phenomena. The study of this SPIF process has already been the subject of several works [6].
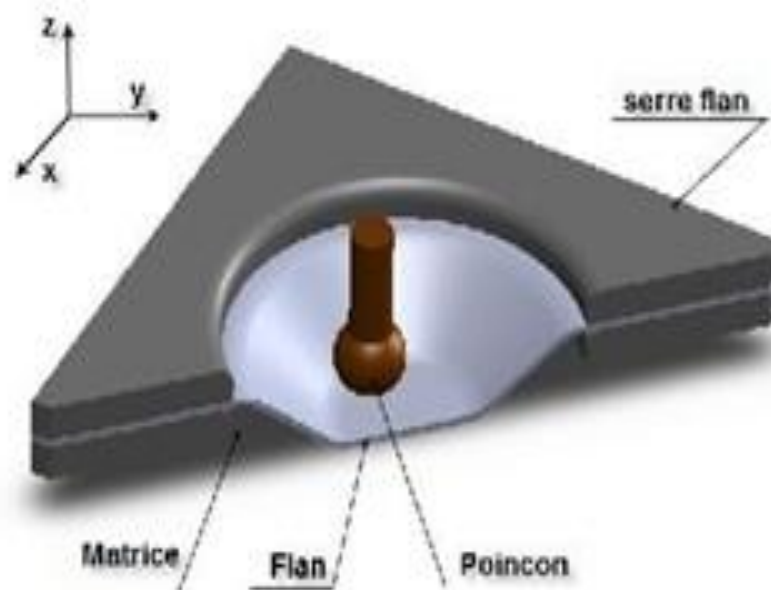
Figure 1. Schematic diagram of one-point incremental forming SPIF

A campaign of experimental tests was carried out by measuring the forming forces during the incremental forming operation. For the measurement of the forces, a force sensor FN7325 was chosen. The tests were carried out on a numerically controlled machine using a hemispherical punch [7].

The machine used is a 5-axis Spinner MVC 850 machining center with a maximum power of 10 kW and a maximum rotation speed of 8000 rpm. This DJENDOUBA ISET machine is equipped with a siemens 840D-SL type computer.

The demand is increasing in recent times for lightweight materials and alloys for use in aerospace applications, driven by the need to produce low-weight vehicles that consume less energy and are equipped with improved fuel-efficiency that produces fewer air pollutants. Aluminum and its alloys, especially aluminum-titanium alloys, are very attractive materials for this type of application due to their high resistance to weight ratio, as well as excellent mechanical properties. Three weight ratios of titanium (10%, 15%, and 20%) were added to aluminum, where it was used in the manufacture of aluminum-titanium alloy [8]. The powder metallurgy cannula was used as a manufacturing method to produce aluminum-titanium alloy. Then the samples were sintered in a horizontal vacuum tube oven for 5 hours at a temperature of 550 ° C. The Jordanian researcher conducted many physical and mechanical tests for aluminum titanium alloy to determine its characteristics such as measurements of true porosity and mass density, X-ray diffraction (XRD) test, scanning electron microscopy (SEM), optical microscopy (OM) test, energy dispersive spectral test (EDS), Microhardness test and wear test. The results of the Jordanian researcher showed that the proportion of titanium has an important effect on the microstructure of the aluminum-titanium alloy, as titanium acts as a softening element for the granules, and thus the aluminum grains have changed from large granules to small granules and then to fine round granules depending on the weight ratio The additive of titanium. Also, the metallic interphase, TiAl, was detected in the sintered samples, which has an important effect on increasing the resistance of

aluminum titanium alloy, by reducing weight loss and thus reducing its wear rates. It has been observed that the surface of the aluminum-titanium alloy has been subjected to two types of wear mechanisms, namely the adhesion wear mechanism and the abrasive wear mechanism [9].

An experimental sheet holding device has been specially designed for incremental forming tests. It is made up of two blocks: a lower flange clamped on the table and a second block containing the blank to be deformed. The holding system and the CNC machine used are shown in Figure 2 [10].

Figure 2. CNC Spinner MCV8501 machining center and SPIF incremental forming device

The FN7325 multi-component sensor associated with an acquisition chain provides the measurements of the forming forces during the test. This sensor can be used to measure forces of up to 5000 N and moments of up to 200 N.m according to the X and Y axes, and forces of up to 250 kN and moments of up to 7000 N. m following the Z axis.

The forming of the sheet is ensured by a hemispherical punch in X160CrMoV12 steel. The latter has undergone a heat-quenching treatment at 1030 ° C and has been air cooled to increase its hardness to 55 HRC. Two values of the diameter of the punch were studied dp = 10 and 15mm. Figure 3 shows the geometry of the punches and the multi-component force transducer used [11].

Figure 3. The tool steel punches (d = 10 and 15mm) and the multi-component force transducer FN73252

The SPIF one-point incremental forming tests were carried out on an ASTM grade 2 titanium, the mechanical characteristics of which are given in table 1. This material is widely used for prostheses because it has great resistance and is perfectly biocompatibility with the system. bony. But little work has been done on the incremental forming of titanium, as this material is more difficult to shape and more expensive than aluminum or stainless steels. It is therefore important to find the parameters involved in improving the process in order to better understand this process and ultimately be able to lead to industrialization. The tests were carried out with sheets of size 200 * 200 mm2, thickness (e) 0.5 mm and 1 mm. The objective was to form buckets with a tilt angle $\alpha= 60°$ [12].

Table 1.

The mechanical characteristics of Titanium T40

Material	E (GPa)		Rp0.2 (MPa)	Rm (MPa)	A%
ASTM grade 2-T40 titanium	1 05	.35	210	350	10

Incremental forming is performed using circular motions in the horizontal plane combined with a displacement step Δz in the vertical plane. The dimensions of the formed bucket as well as the parameters of the incremental forming test are shown in Figure 4. Thepunch-sheetlubricantusediscuttingoil [13].

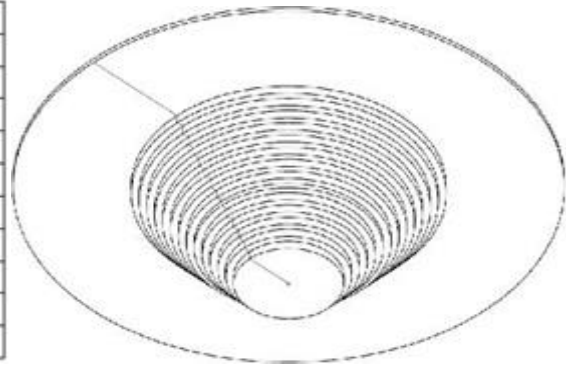| Conditions of realization	
Material	T40
Large diameter ØD	100 mm
Height h	25 mm
Thickness e	0.5 mm
Cone angle α	60°
Increments Δz	0.5 mm and 1 mm
Punch diameter d_p	10 mm and 15 mm
Rotation speed N	800 rpm
Feed rate VF	400 mm /s
Lubrication	in oil

Figure 4. Shape of the bucket to be made and test conditions

Two tests are performed in this study. For the first test, the value of the displacement step of the punch is $\Delta z = 0.5$ mm and the tool diameter $d_p = 15$ mm. The measurements of the forces noted are presented in Fig. 5. Cracks appear from the 15th contour on the outer surface of the bucket [14].
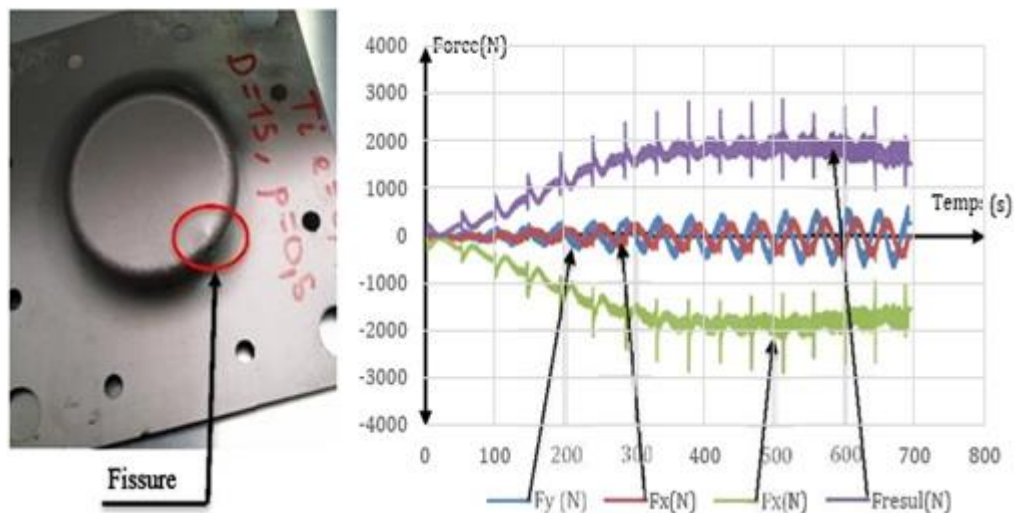

Figure 5. Forming forces for $\Delta z = 0.5$mm and dp = 15mm

The second test is carried out with a displacement step $\Delta z = 1$mm and a tool diameter $d_p = 10$ mm. The measurements of the noted forces are presented in figure 6. As for the first test, cracks appear but from the 8th turn. These results are consistent with work in which a limit angle of inclination of the wall of 56 ° is found, from which damage occurs.
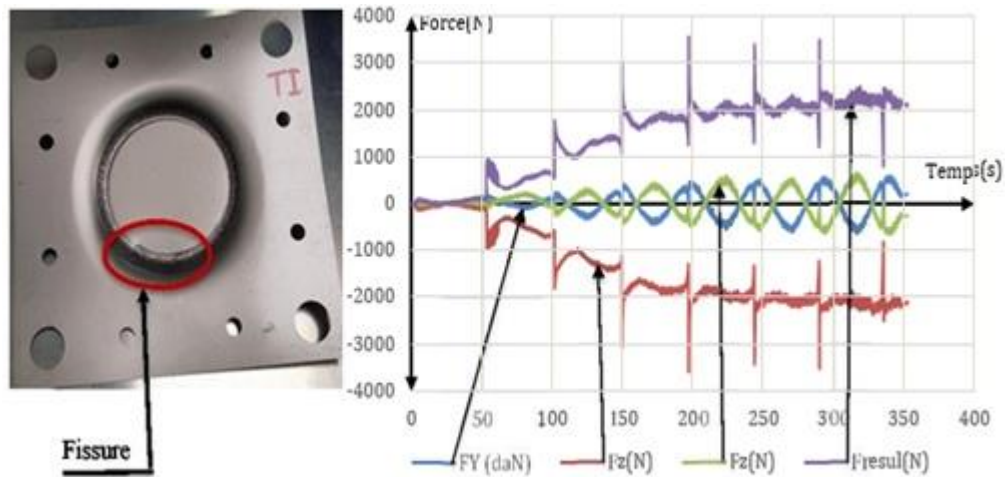
Figure 6. Forming forces for $\Delta z = 1$ mm and $d_p = 10$mm

As can be seen from these curves, the forces to shape titanium sheets are of the order of 2000N and they are greater than those of aluminum (around 800N). Care in the choice of the design machine is therefore necessary when forming titanium sheet in order not to damage the material. In Figure 6, we can note that the surface condition of the part is not optimal. Optimization of process parameters is necessary in order to improve the surface finish of the formed parts [15].

The numerical simulation of the process was carried out with ABAQUS/Explicit. A model of elastoplastic behavior of Swift type $\sigma = K (\varepsilon_0+\varepsilon^P)^n$is used. The parameters of the model are presented in Table 2.

Table 2.

Plastic properties of grade 2 titanium

n	K	ε_0
0.084	570	0.00157

The sheet with a grid with thin shell elements at 4 nodes has reduced integration of the S4R type. Tools are considered rigid domains. Figure 7 shows the evolution of the forming forces predicted by the numerical simulation. It should be noted that the curves of the numerical prediction are similar to the experimental results, but differences exist and they are linked to the fact that the numerical simulation of the incremental titanium forming process was carried out with a

simplified model not taking into account the material anisotropy, damage, blank tightening conditions, tool deformability. The iso-values of the cumulated plastic deformation and the distribution of the final thickness of the part along the axis of symmetry are given in figure 8. We note a strong localized plastic deformation and a strong thinning on the contour of the bottom of the formed part.
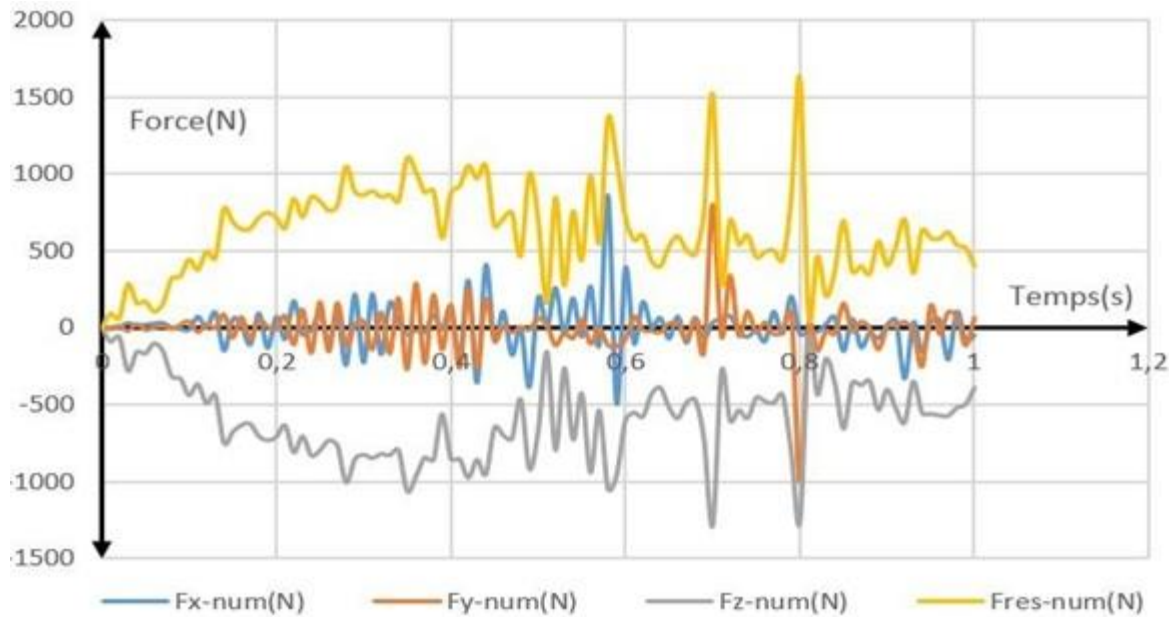

Figure 7. Allure of the forces of the numerical simulation of T40 (e = 0.5mm; d_p = 15mm; Δz = 0.5mm)
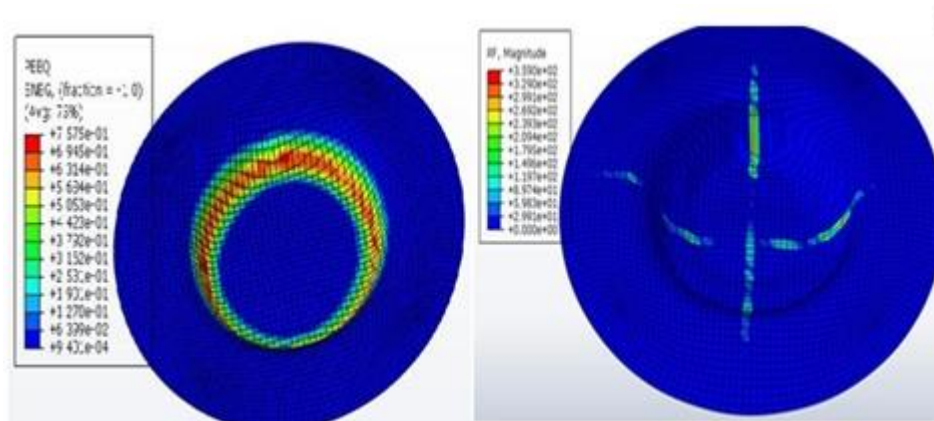

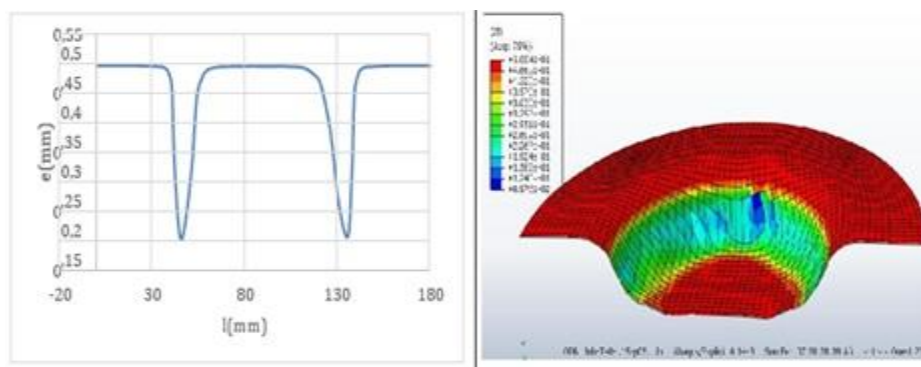Figure 8. The distribution of the resulting force and plastic deformations

Figure 9. The distribution of the final thickness of the part along the axis of symmetry.

In this paper, an experimental study and numerical simulation of the incremental forming of titanium sheets was carried out. Forming forces are measured experimentally and compared to the values of the numerical prediction. This experimental study showed the need to optimize the process parameters in order to avoid damage to parts and to improve the surface finish of the part. The next work will focus on performing hot tests in order to reduce the forces during the test and increase the ductility of the sheet and improve the thickness distribution.

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ЭКСПЕРИМЕНТАЛЬНОЕ И ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ СИЛ ПРИ ИНКРЕМЕНТАЛЬНОМ ФОРМОВАНИИ ТИТАНОВЫХ ЛИСТОВ

Аль Дарабсе Амер Мохаммад Фархан

Инженер самолето-и-вертолетостроение

и Электроснабжение

amersamarah4@gmail.com

Маркова Елена Владимировна, к.э.н., доцент

кафедры «Общенаучные дисциплины»

morozova319@yandex.ru

Денисова Татьяна Валентиновна, к.э.н., доцент

кафедры «Экономика, управление и информатика»

denisovaiatu@mail.ru

Институт авиационных технологий и управления, Ульяновский государственный технический университет, г. Ульяновск, РФ

Аннотация. Постепенное формование – это процесс быстрого прототипирования, который позволяет формовать листы без использования формующих инструментов с помощью станка с числовым программным управлением. С помощью этого процесса можно создавать самые разные формы. Целью данной работы является изучение посредством экспериментальных испытаний и численного моделирования поведения титана марки ASTM 2 во время инкрементного точечного формования (SPIF). Обрабатывающий центр Spinner MFG850 от ISET в JENDOUBA, соединенный с многокомпонентным датчиком силы FN7325, использовался для формования тонких листов с помощью этого процесса. Поскольку диаметр пуансона и его инкрементное перемещение являются параметрами, оказывающими непосредственное влияние на силу формования, были проведены испытания с диаметрами пуансонов dp от 10 до 15 мм и различными траекториями, состоящими из круговых перемещений в горизонтальной плоскости экспериментально. Численное моделирование выполняется при больших упругопластических деформациях с помощью ABAQUS / explicit. Проведены сравнения эволюции формовочной силы для различных значений диаметра пуансона dp и шага перемещения Δz.

Ключевые слова: инкрементальная формовка, титан, конечные элементы, эксперименты, приборы.