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# Investigations of the microstructural response to a cold forging process of the 6082-T6 alloy

J. Bouquerel [a], B. Diawara [a,b,c], A. Dubois [b], M. Dubar [b,*], J.-B. Vogt [a], D. Najjar [c]

[a] Université Lille Nord de France, ENSCL, UMET, CNRS, UMR 8207, F-59655 Villeneuve d'Ascq, France
[b] Université Lille Nord de France, UVHC, TEMPo EA 4542, F-59313 Valenciennes, France
[c] Université Lille Nord de France, EC Lille, LML, CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France

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ABSTRACT

The microstructure of 6082 aluminium alloy in artificial aged condition was investigated before and after cold forming. The cold forming process was performed at room temperature with and without lubricant. An in depth microstructure investigation has been carried out through electron backscatter diffraction (EBSD) analysis. Different approaches were considered to quantify the plastic strain: the Line Segment Method (LSM) and the study of misorientations trough the Kernel Average Misorientation (KAM), the Grain Orientation Spread (GOS) and the Grain Average Misorientation (GAM). The evidence of intermetallic particles removal from their location during plastic deformation was observed. Values of plastic strain lower than 0.1 did not affect the grain size itself. Nonetheless it induced the development of sub-structures which may lead to the hardening of the alloy.



## 1. Introduction

Looking for lightweight components is a challenge of major importance In the transport industry. Indeed, mass reduction is one of the responses to the Kyoto Protocol which aims to tackles the emissions of six greenhouse gases, including the carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and some fluoride gases. As most of the forces applied on a vehicle are proportional to its weight, a reduction in mass implies a reduction of the driving force and consequently a reduction in energy consumption. Moreover a light car is also safer since it possesses a smaller inertia and will require a shorter distance to stop than a heavy car. Getting mass reduction of the vehicles is closely related to the use of light materials such as aluminium alloys [1,2]. The 6xxx alloys have been extensively studied because of their technical importance and their exceptional increase in strength obtained by precipitation hardening. They are also largely used in automotive and aeronautic components because of their impact on weight reduction.

Those alloys contain magnesium and silicon as major addition elements, which are partly dissolved in the primary $\alpha$-Al matrix, and partly present in the form of intermetallic phase [3–6]. Fe is also present as an impurity in the commercial alloys and leads to a wide variety of Fe-containing intermetallics [7–9]. The relative volume fraction, chemical composition and morphology of these structural constituents have a deep impact on the material properties.

Among the other 6xxx alloys, the 6082 alloy stands out due to its combination of higher mechanical properties, excellent corrosion resistance and good weldability [10,11]. However, the high strength of the 6082 alloy limits its formability and requires higher forces in forming operations. Hence, before forming some annealing steps at high or moderate temperatures are required to improve the material ductility. Nevertheless, in addition of being time and energy consuming, elevating temperature may induce deformation and modification of the final product geometry among other parameters.

Within the last decades, the properties of the 6082-T6 alloy have been extensively investigated in terms of microstructure evolution within thermo-mechanical processing [12–16], welding [17,18] as well as grain refinement associated to severe deformation [19–22]. However, there is few works carried out on the cold forging of this material [23–25].

Cold forming at room temperature is an alternative to these problems. Cold forging is a process suitable for manufacturing low-cost and high quality automotive components made in high strength aluminium alloys [23]. This method is peculiarly appropriate for parts with narrow geometrical tolerances, good concentricity, smooth surface finish and for near net shape products.

* Corresponding author. Tel.: +33 327511391; fax: +33 327511411.
*E-mail addresses:* jeremie.bouquerel@univ-lille1.fr (J. Bouquerel), bmdiawara@yahoo.fr (B. Diawara), andre.dubois@univ-valenciennes.fr (A. Dubois), mirentxu.dubar@univ-valenciennes.fr (M. Dubar), jean-bernard.vogt@univ-lille1.fr (J.-B. Vogt), denis.najjar@ec-lille.fr (D. Najjar).

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Forming processes are characterised with a wide range of strain and strain rates. The degree of plastic deformation near the surface in the forming process is crucial when determining the mechanical and microstructural features of the work-piece surface, because the degree of plastic deformation strongly affects the development of grain structure in recrystallization. In addition, most of material failures come from the outer layers of the work piece (wear, fatigue, fretting damage, corrosion etc.). These phenomena are all extremely sensitive to the structure and to the properties of the surface of the material [26]. The investigation of the local plastic strain distribution occurring during forming allows a clear understanding of the effects of the macroscopic plastic strain on the local plastic strain gradient. Moreover, understanding these effects will not only contribute to develop guidelines in controlling deformation parameters (macroscopic plastic strain and strain rate) during surface plastic deformation processes but also predict the microstructure changes induced by cold forming that play a crucial role for mechanical failure and wear of materials [10].

The aim of the present work is to understand the effect of cold forging on the microstructure changes of the 6082 aluminium alloy. Hence the laboratory developed Upsetting Sliding Test, which is able to reproduce a large variety of industrial forming processes, has been used. Here, the system focuses on conditions similar to those present in the vicinity of the blank holder during stamping or deep drawing process. The local strains have been estimated by FEM calculation prior to tests and their distribution were validated by means of advanced analysis tool such as Electron Back-Scatter Diffraction on a scanning electron microscopy (SEM-EBSD). The different process parameters, such as lubrication, penetration levels were investigated and some microstructure based criteria were adopted.

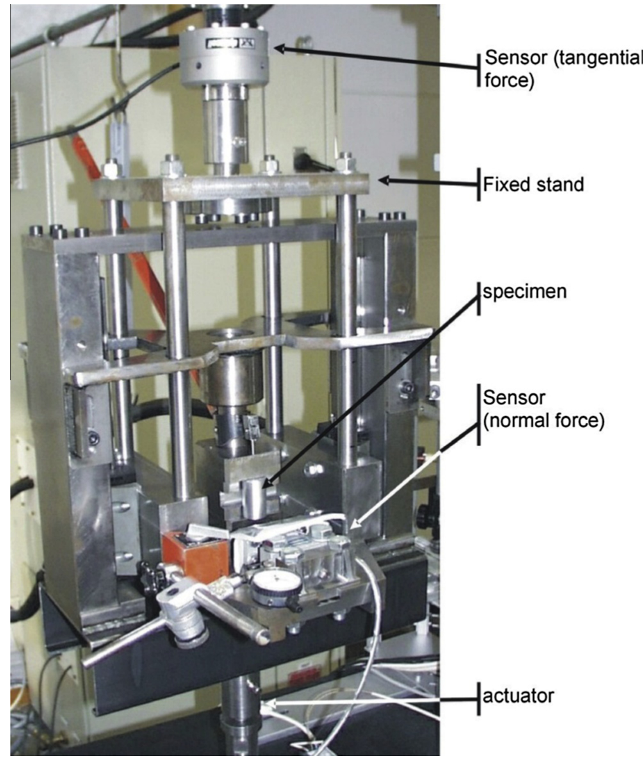


**Fig. 2.** Upsetting sliding test stand.

## 2. Experimental procedures

### 2.1. Cold forging testing

Cold forging tests are carried out on the Upsetting Sliding Test (UST) (Figs. 1 and 2), developed at TEMPO Laboratory in order to simulate physical and mechanical contact conditions of cold forging processes [27]. This testing stand allows simultaneous compression and translation movements. It is positioned on a classical servo-hydraulic tensile machine and it is composed of two parts: a moving part that is supported by a load cell and a fixed one integrated on the tensile machine. The contactor that represents the tool is arranged on the moving part, and the specimen that represents the workpiece is clamped on the fixed part. The cylindrical geometry of the specimen, used in previous works [27], has evolved to a plate structure and the fixed stand has been slightly modified to welcome this plate specimen. Although this test is mainly dedicated to tribological analyses [28,29], its abilities to apply high contact pressure and to generate high plastic strains make it an efficient device to simulate forging sequences, *keeping the advantages of a laboratory facility*.

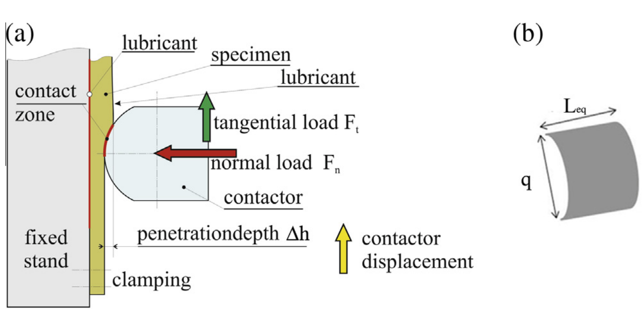


**Fig. 1.** (a) Schematic illustration and main parameters of the UST and (b) equivalent surface of contact.

The principle of the test is rather simple and proceeds in two steps:

(1) Before the beginning of the test a relative penetration between the extremity of the contactor and the surface of the specimen is adjusted.
(2) The test starts and the contactor moves up towards the specimen. The contactor contacts the specimen and rubs straight on it, generating a locally deformed part.

Both normal ($F_n$) and tangential ($F_t$) forces are recorded during the test. Fig. 3 presents the typical evolution of the normal and tangential forces curves during the cold forging of the 6082 aluminium alloy. From these curves, it can be observed no contact occurs before 55 mm. This step is used to allow the increase of the contactor speed from zero to the desired value. As a consequence, when contact occurs, the contactor speed is constant, and remains constant until the end of the test. At a distance ranging from 55 mm to 65 mm the contactor enters in contact with the specimen, leading to an increase of the loads (zone A). Between 65 mm and 85 mm forces have a monotonic behaviour. This region (zone B) corresponds to the sliding area. Beyond 85 mm (zone C), the contactor starts leaving the contact and the forces abruptly decrease to zero.

The mechanical analysis of the upsetting sliding test leads to the mean normal contact pressure $\sigma_n$ and to the mean tangential stress $\sigma_t$, as determined by the following equations [30]:

$$\sigma_n = \frac{F_t \Delta h + F_n q}{L_{eq}(q^2 + \Delta h^2)} \quad (1)$$