Materials Science & Engineering A 618 (2014) 490–495

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

# Evaluating the mechanical behavior of hot rolled Al/alumina composite strips using shear punch test

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ARTICLE INFO

*Article history:*
Received 10 April 2014
Received in revised form
31 August 2014
Accepted 5 September 2014
Available online 16 September 2014

*Keywords:*
Shear punch test
Hot rolling
Annealing treatment
Strain hardening
Alumina reinforcement
Mechanical properties
Shear failure surface

ABSTRACT

The evaluation of mechanical properties, like yield and ultimate shear strengths from shear punch tests, is important when availability of material, is limited. A shear punch test setup was built, and the mechanical properties of different strips of hot rolled pure aluminum, post-rolling annealed pure aluminum, as-milled pure aluminum, and 4 wt% $Al_2O_3$ were investigated. The materials were first manufactured using powder metallurgy and then processed by hot rolling procedure. Microstructures of the samples were investigated by optical and scanning electron microscopes. It was found that by increasing alumina content in the matrix, shear strength and hardness were increased; also, the percentage of shear elongation was decreased. The results, also, indicated that by applying mechanical milling on pure aluminum powders before the hot rolling process, shear strength and hardness increased more than other samples. Moreover, shear strength was increased by increasing the amount of alumina particles in composite strips. SEM observations demonstrated that the amount of flat surface in shear failure micrographs increased by increasing the amount of shear strength and hardness.


## 1. Introduction

The shear punch test (SPT) is a mechanical test technique in which a thin strip specimen is clamped between a set of dies which are blanked using flat cylindrical punch at a slow constant speed [1]. The specimen deformation occurs in the small annular zone between the punch and the die. The load–displacement curve (LDC) obtained during the slow blanking operation is very similar to that obtained in a conventional uniaxial tensile test [2]. Some mechanical parameters such as the shear yield strength (SYS), ultimate shear strength (USS), and shear elongation percentage ($\%\varepsilon_u$) values can be calculated from the SPT data [3]. A linear correlation between tensile and SPT shear strengths has been reported [4,5]. The SPT has been used for testing nuclear irradiated materials [6], biomaterials [7], and composites [3] by several researchers. Some researchers [8] modeled the SPT using finite element analysis (FEA). The authors [9] of this study, however, introduced the powder metallurgy and hot rolling processes as a new solid state technique for manufacturing aluminum/alumina composite strips. These processes were used for producing high uniform AMC strips.

In this study, the effect of post rolling annealing, strain hardening, and the amount of reinforcement on the mechanical behavior of Al/alumina composite strips which were produced using powder metallurgy and hot rolling processes, were investigated. Although the tensile test is the most general method of evaluating the mechanical properties of materials, because of the small size of fabricated samples, the researchers preferred the shear punch test.

## 2. Experimental procedures

### 2.1. Materials and procedures

Commercial aluminum powders with ~93.8% purity, and particle size of < 40 μm, and $Al_2O_3$ powders with 3–8 μm particle size and polyhedral shape were used as raw materials. The chemical composition of aluminum powders used in this study is shown in Table 1. Specifications of alumina powders are also given in Table 2. Aluminum powders were mixed with 2 and 4 wt% of $Al_2O_3$ in a high energy planetary ball mill with 400 rpm for 300 min. In this process, balls made of hardened D2 tool steel with different sizes were used. Mechanical milling was done under neutral gas control. Stearic acid [9] was used as a process control agent (PCA) material with a proportion of 0.8–1 wt% of the total powders [9]. Also, pure aluminum powder particles were ball

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http://dx.doi.org/10.1016/j.msea.2014.09.037
0921-5093/

milled lonely under the same conditions. Powder samples were pure aluminum, milled pure aluminum, and aluminum milled with 2 and 4 wt% alumina powder particles. These samples were pressed at an initial pressure of 100 MPa and then hot pressed at 200 MPa in a graphite die. The compressed powders were then sintered at 773 K for 45 min under vacuum condition. Graphite emulsion was used as a lubricating material for the die wall and the bottom of punch. After sintering in a vacuum hot press die, specimens were cut perpendicular to the compression axis. Hot rolling experiment of slices was performed using a laboratory rolling mill with a loading capacity of 20 t. Samples were heated at 723 K for 6 min in a cylindrical resistance furnace for each cycle of hot rolling. The above process was further repeated so that the final thickness of strips reached to 1 mm.

Hot-rolled pure aluminum samples were annealed in a resistance furnace at 673 K for 120 min. These specimens were cooled gradually in air.

### 2.2. Investigation of mechanical properties

#### 2.2.1. Shear punch test

In order to investigate the effects of annealing treatment, mechanical milling, and addition of reinforcement particles on mechanical properties of composite strips, the shear strength and ductility were assessed at a cross head speed of 0.2 mm/min at room temperature. Fig. 1 shows schematic view of SPT equipment. Sample size was limited within 20 (length) mm × 15 mm (width) × 1 mm (height). Shear punch apparatus consisted of an upper and lower housing. The upper housing contained a punch, and the lower one held a die. The modeling procedure, developed by the authors, was used to design and to assemble this equipment has been done by CATIA® software. The material selected for both the punch and die was AISI D2 air hardened tool steel (60 ± 2 HRC). The central axes of the punch and die were exactly in the upper and lower housing; they were adjusted by the cross table that was installed at the bottom of this instrument. The specimen was placed between the die and a washer which was fitted by two bolts. A flat tip punch was forced through the specimen, and the act of punching against the die that sheared a circular disk from the specimen, completed the test. The punch device can be constructed for any punch size. However, a punch of 3 mm diameter and die of 3.04 mm diameter were used for the present study. The SPTs were performed on a Hounsfield H25KS testing machine. Three tests were carried out on each specimen; the average values are reported here.

During the test, the load $P$ on the punch was measured as a function of the punch displacement $\delta$. The average shear stress $\tau$ was calculated using the following equation [5]:

$$\tau = P/2\pi rt \quad (1)$$

where $t$ is the specimen thickness and $r$ is the average of the punch and die radii.

Guduru et al. [5] founded a linear correlation between the shear and tensile data for yield and ultimate strengths. They are

$\sigma_{0.02} = \alpha\tau_{1.00}$ where $\alpha = 1.77$ and,
$\sigma_{UTS} = \beta\tau_{USS}$ where $\beta = 1.80$.

Also, Toloczko et al. [10] proposed other relationships between the strain hardening exponent obtained from the shear punch data and the uniform elongation. Briefly put, they are

$$(n_\tau/0.002)^{n_\tau} = \tau_{USS}/\tau_{SYS} \quad (2)$$

and,

$$\varepsilon_u\% = 2.26n_\tau - 0.15 \quad (3)$$

where $\varepsilon_u$% is the uniform shear elongation, $n_\tau$ is the strain hardening exponent in SPT, and $\sigma_{0.02}$ and $\tau_{1.00}$ describe the estimated 0.02% tensile and the 1.00% SPT normalized displacement offset yield point, respectively. They experimentally proved these relations for aluminum alloys, too. The scattering in the values of shear elongation (%) was reported in Table 3.

#### 2.2.2. Hardness measurements

Brinell hardness test measurements of the samples were performed, corresponding to ASTM-E-10-10 [11], under a load of

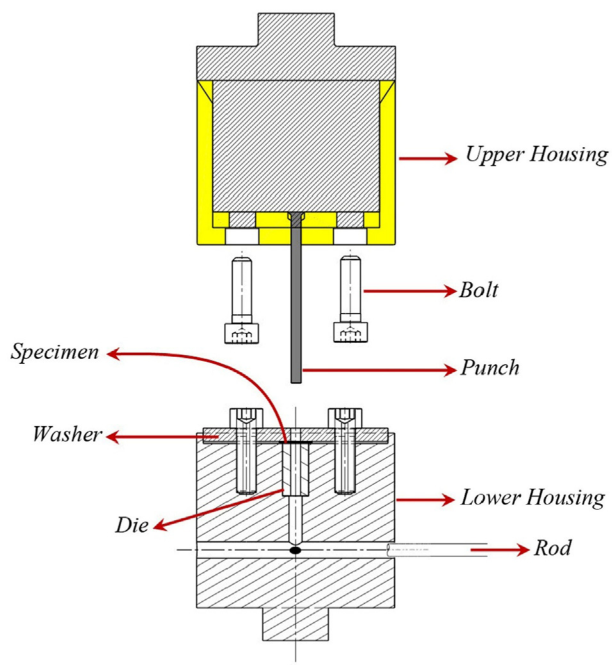


**Fig. 1.** Schematic of shear punch test equipment.

**Table 1**
The chemical composition of aluminum powders [9].

| Element | Line | Intensity (c/s) | Error 2-sig | Conclusion | Units | Voltage = 20.0 kV Take off Angle 35° |
|---|---|---|---|---|---|---|
| Al | Ka | 980.20 | 6.710 | 93.789 | wt% | |
| P | Ka | 3.00 | 0.680 | 0.659 | wt% | |
| Ag | La | 6.99 | 0.814 | 4.145 | wt% | |
| Te | La | 1.86 | 0.627 | 1.406 | wt% | |
| | | | | 100.000 | wt% | Total |

**Table 2**
Alumina powders specifications [9].

| Average particle size | Type of crystal | Melting point [°C] | Young's modulus [GPa] | Density [g cm$^{-3}$] | Heat conductivity [Wm$^{-1}$ K$^{-1}$] | Mohs-hardness | Thermal coefficient of expansion [$10^{-6}$ K$^{-1}$] |
|---|---|---|---|---|---|---|---|
| 3–8 μm | Hexagonal | 2050 | 410 | 3.9 | 25 | 6.5 | 8.3 |