1. Introduction
The competitive properties provided by ductile cast iron are industrially well-known. Inside ductile cast iron, a series of foundries are distinguished commonly characterized by the graphite in spheroidal form in their matrix. This is the reason why ADI castings is one of these castings with very particular microstructure that offers superior mechanical characteristics (high design flexibility, elevated resistance against weight, good tenacity, fatigue and wear resistance, and additionally, cost-effective solution).

During the last decades, the understanding and control of the complex and rigorous thermal process associated to ADI production lead to the introduction of ADI castings in a variety of industrial sectors [1].

This material is increasingly demanded by engineers for demanding tasks in terms of strength resistance, wear, or fatigue. Their mechanical properties are superior to pearlite ductile castings and forged steels and thus, they are highly appreciated for high commitment parts (moving parts and critical components). The use of ADI castings at an industrial level can be found in many different applications in industrial sectors such as automotive. Additionally, a great effort has been made to standardise castings to different degrees, as reflected in ISO 1083:1997 [2,3]. In contrast, many manufacturing challenges remain such as the low machinability compared with other cast materials.
Traditionally manufacturing steps are performed before performing the heat treatment, which is very productive for roughing and low-dimensional requirements, but it is not feasible for complex geometries [4]. Moreover, some studies about turning ADI using carbide cutting tools observed the tendency to crater wear mechanisms during the machining process, causing adhesion and, consequently a premature tool wear [1,5].

Some previous work was performed by the authors defining a two-stage testing procedure for analysing different grades of inserts related to turning difficult-to-cut materials [6]. In addition, in the way of offering a more productive solution to turning ADI castings, this procedure was applied into ADI material comparing carbide, mixed and ceramic inserts, analysing cutting forces and tool wear mechanisms, in order to evaluate the feasibility of using ceramic inserts in dry turning of casting ADI 1000 [7], in terms of optimal cutting parameters, cutting forces and tool life [8].

Following the same researching line and based on previous works, the novelty of this work stems from the analysis of mixed ceramic inserts feasibility from the material side. Starting from the optimal defined cutting parameters applied to ADI 1000, the cross-section, residual stresses and microhardness are evaluated to present ceramic cutting tools as a possible solution to obtain a more productive process manufacturing ADI materials, considering results from the machining processes (previous work) and from the machined surface point of view.

2. Experimental Procedure
The defined methodology includes experimental design and results. The first step consists of defining different cutting parameters in order to analyze the feasibility of using Ceramic inserts on turning ADI materials.

Longitudinal turning experimental tests were performed using a multi-tasking turning center of CMZ© (TC25BTY) power 22 kW with a Fanuc© (type 31iT LVH) NC and an initial blank dimension of 150 mm of diameter and a 400 mm of length. The material used is a Austempered Ductile Iron presented in automotive and critical safety industries. It is defined by the standard EN 1564 PNE GJS as EN-GJS-1000-5; presenting a tensile strength of 1000 MPa and yield strength of 700 MPa. Material composition is (in wt.%): 3.56% C, 2.18% Si, 0.22% Mn, 0.021% P, 0.007% S, 0.063% Mg, 0.76%Cu, 1.9% Ni, 0.24%, Mo, and the balance iron. Additionally, austenitization at 900ºC and austemperization in molten salt at 400ºC as a heat treatment was performed before the cutting process. Each test was repeated five times. In each test a new cutting edge was used and only was used for one pass.

Table 1 shows the cutting velocity (v_c), feed (f) and depth of cut (a_p) selected for the experimental set-up.

Table 1. Cutting parameters definition

| vc [m/min] | f [mm/r] | a_p [mm] | Cutting fluids |
|-----------|---------|---------|---------------|
| 280       | 0.1     | 1.5     | Dry           |

Selected cutting tool consisted on a mixed ceramic insert RNGN 120700 according to [8]. According to ISO designation, these are round inserts diameter 12.7 mm, neutral themselves with relief flank angle of α = 0º. These types of inserts present added carbides to improve the toughness and thermal conductivity. Finally, figure 1 shows the experimental set-up and the measured cutting forces during the turning process.

3. Results and discussions
The cross-section, residual stresses, and microhardness of the final surface was measured and evaluated. Sections 3.1, 3.2 and 3.3, presents the results in detail.

3.1. Cross-section analysis
To obtain the cross-section, a microscope Nikon OPTIPHOT100 was used. Figure 2 shows obtained captures in three different scales.
3.2. Residual stresses
To measure residual stresses in the final surface hole-drilling strain gage method was selected. The rosette type selected was 062 UL with a mean diameter of 5.13 mm, the hole diameter was 1.94 mm and a limit depth of 0.75 mm. The relation between hole diameter and maximum depth is $0.75/1.94 = 0.386$. In line with ASTM standard E837 [9], when applying this blind hole drilling the relation between hole diameter ($D$) and maximum hole depth ($Z$) is defined as $Z/D = 0.4$.

Figure 3 shows graphically the obtained values for X and Y axes, where the X represents the cutting speed direction and the Y the feed rate direction. Hence, where the chip is removed the compressive stresses presents lower values. However, the y compressive stress values are considerably higher due to the mixed ceramic insert geometry, being round inserts which helps the cutting process to generate compressive stresses. These compressive stresses present better behaviour to fatigue failure.

3.3. Microhardness
Microhardness measurements, used the ASTM standard E384 [10] that defines micro indentation hardness testing. Figure 4 shows the Vickers indenter used and the obtained results. According to the
ASTM standard E140 [11], these values were converted internally into Rockwell units because they are more commonly used for these materials.

A high value of the Microhardness is found from 53 to 42 HRC along the first mm of depth, after that it is stabilised aligned with the common hardness value for this material, around 41-42 HRC. This increment of hardness value is coherent with the compressive residual stresses results. Moreover, these values are also related to the deformed layer presented in the microstructure; this deformation is derived from the pressure generated by the tool behaviour in the feed rate direction.

Obtained microhardness properties enforce some of the main ADI characteristics described in the introduction as good tenacity, fatigue, and wear resistance.

![Figure 3. Measured residual stresses.](image)

![Figure 4. Microhardness measurements average.](image)
4. Conclusions
Before machining, Austenitic Ductile Iron (ADI) casting are known to present good mechanical properties and wear and fatigue resistance, allowing its use for designs with reduced weight and size components. However, these properties are reported in the literature affecting the material machinability, especially in higher grades of ADI.

Therefore, the main conclusions derived from this work are related to the surface integrity feasibility of using mixed ceramic inserts in turning ADI materials. Several conclusions are described hereafter:

• In this study, the feasibility of using mixed ceramic inserts in the dry turning of casting ADI 1000 (EN-GJS-1000-5) is evaluated. Related to the cross-section, it was observed a common ADI microstructure, presenting a deformed layer and a heat affected zone, not over 20 µm. These results are thought to be derived from the elevated temperature generated during the process.
• Over the first millimetre in depth it was found a compressive residual stress, which supports the feasibility of this cutting tools because these values are related to better behaviour against fatigue and reduce the possibility of fragile failure.
• Regarding microhardness, the obtained value presents higher hardness within the first millimetre, before achieving the standard hardness value for this material. These results are also offering better mechanical properties.

So, mixed ceramic inserts provided the best performance in terms of cutting forces and tool life comparing with other ceramic inserts [8]. Additionally, this study presents extra information about the machined material showing the behaviour of the proposed solution in terms of surface integrity.

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