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Determination of Residual Stresses in Roll Compacted Titanium Strips

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Abstract

Manufacturing processes typically produce residual stresses. The residual stresses can be advantageous when they are compressive and detrimental when tensile. In roll compaction of metal powder, similarly to rolling solid metals, substantial residual stresses can be generated. In roll compaction of metal powders, few studies have been done to identify the presence of any residual stresses, their effects on the process that produced them and subsequent processes. In this study, residual stress induced during roll compaction of titanium strips were measured for strips of different densities. The different densities were achieved by rolling two different particle size (100 and 325 mesh) titanium powders varying the roll gap (0.1, 0.3 and 0.5mm) and the set strip width (20, 50, 100 mm). The roll speed was kept constant at 10 rpm while three feed rates were employed i.e. 15 g/s for 20mm strip width, 30 g/s for 50mm strip width, and 60 g/s for 100mm strip width. The strips were evaluated for surface residual stresses using x-ray diffraction (XRD) surface probing technique. Preliminary results were obtained for the surface residual stress at the center of the titanium strips for the 100 and 325 mesh strips rolled at 0.1 roll gap for 20 and 50mm set width. Results show the presence of largely compressive residual stresses. The largest surface residual stress of -55 MPa was recorded corresponding to a compaction density of 83 %. The corresponding maximum shear stress was 27 MPa. Lower green density resulted in progressively more tensile residual stresses although all stresses remained compressive for the investigated parameters.

Keywords: Titanium powders; density; Residual stress; X-ray diffraction

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1. Introduction

Titanium metal is known for its high strength-to-weight ratio advantage over other structural materials like steel and light metals such as aluminum [1, 2]. It also has other excellent properties such as good corrosion resistance and biocompatibility. This makes it favorable for use in many applications. However, this material finds use mostly in applications such as aerospace or medical and minimal use in other applications. This is due to the high cost of the titanium metal. This high cost is due to difficulties associated with the processing/extraction of titanium and the machining of the metal [3]. Alternative low cost processing methods that can reduce the cost of titanium would improve the application of titanium in more widespread industries.

Powder metallurgy is a process that is known to reduce costs [4, 5]. This is due to its ability to make near net or net shape components with minimal or no machining requirements. There are several powder metallurgy techniques such as press and sinter (P & S), metal injection molding (MIM), extrusion, forging, direct powder rolling (DPR) and others. These processes offer different advantages such as production of net shapes that are small and complex in bulk quantities such as in MIM and semi-finished flat products such as plates, sheets and strips as obtained in DPR. Direct powder rolling (DPR) is a powder metallurgy process that can be used to make flat mill products such as plates, sheets, coils and strips [6, 7, 8]. This process involves several stages and currently two routes are known. One route involves roll compaction, thermal treatments/sintering and post sintering treatment such as cold rolling and/or annealing (ADMA) [9]. The other route includes roll compaction, thermomechanical treatments/hot rolling and post hot rolling treatment such as cold rolling and/or annealing [7, 8]. The roll compaction stage is a critical stage in regards to achievement of full density and dimensional stability of the compacts during roll compaction and in the subsequent processing stages. High green densities assist in achieving full density without applying extreme thermal or thermomechanical conditions. Dimensional stability assists with the retention of 'flatness' for the strips during processing. Dimensional distortions can be caused by differing shrink rates due to varying densities within a strip during thermal treatments. They can also be caused by residual stresses induced by the manufacturing process or relaxation of the residual stresses during thermal processing [11-17].

Residual stresses can be defined as stresses that remained locked up in a component after processing and all externally imposed loading has been removed [18]. Processes that can introduce residual stresses include mechanical, thermal, and chemical processes. Mechanically generated residual stresses are due to manufacturing processes that produce non-uniform plastic deformation. They can develop naturally during processing or introduced to attain particular stress profiles in a component. Thermally generated residual stresses are due to non-uniform heating or cooling. In large components this can lead to severe thermal gradients and the development of large internal stresses. The chemically generated stresses can develop due to volume changes associated with chemical reactions, precipitation, or phase transformation.

There are several techniques that can be used to study residual stresses in a component. These range from the destructive techniques to nondestructive techniques. The mechanical stress measurement methods include Curvature Analysis, Hole Drilling [19] and Compliance Methods. There is also magnetic and electrical methods, ultrasonic methods, thermoelastic methods, photo elastic methods, and diffraction methods such as neutron diffraction, synchrotron diffraction and X-ray diffraction [20-21]. Nondestructive diffraction stress measurement in general is based on probing the lattice plane separation distance in a material which depends on the applied loading. This translates to induced strain when compared to the stress free lattice plane separation distance. The XRD method specifically measures the average stress for depth levels of 5 - 7 μm due to limited energy levels. However, for assessment of surface stresses, this is adequate.

Roll compaction is a mechanical process which can result in residual stresses if non uniform deformation occurs. There are few studies that have been carried out to understand residual stresses induced in roll compaction, hence efforts to study this area would be beneficial. Researchers showed that alligatoring during roll compaction of powders can occur due to residual stresses [22]. Other researchers have stated that variations in residual stresses can lead to distortions in subsequent sintering process [14-17]. Consequences of these residual stresses can lead to defects or loss of flatness of the strips. It is important to determine the presence of residual stresses in the roll compacted strips. In this study, the presence of residual stresses on roll compacted strips was investigated and how they vary with compaction density. Preliminary measurements were done at the center of the strips for the 100 and 325 mesh powders rolled at 0.1 roll gaps with a set width of 20 and 50mm.