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Development of high speed steel sintered using concentrated solar energy

G. Herranz[a,*], A. Romero[a], V. de Castro[b], G.P. Rodríguez[a]

[a] Universidad de Castilla-La Mancha, Metallic Materials Group, ETSII-UCLM, Avda. Camilo José Cela s/n, E-13071 Ciudad Real, Spain
[b] Universidad Carlos III de Madrid, Departamento de Física, Avda. de la Universidad 30, E-28911 Leganés, Madrid, Spain

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ABSTRACT

The steel powders were sintered under N_2–H_2 atmosphere in a solar furnace and in a Fresnel lens, after compaction of the green parts, using much higher heating and/or cooling rates as compared to conventional tubular furnace. The effects of processing parameters and the use of concentrated solar energy on densification and mechanical properties were analyzed. Experimental results demonstrated the activating effect of concentrated solar energy on the sintering process showing that an optimum densification is achieved at 1150 °C on both solar installations in just 90 min for the solar furnace and in 30 min in the case of Fresnel lens installation compared with an optimum temperature of 1290 °C in ∼10 h of total cycle in the conventional tubular furnace. Better mechanical properties were obtained using concentrated solar energy with microhardness measurements ranging between 800 and 900 HV. Microstructural analyses by scanning and transmission electron microscopy reveal the presence of submicron sized vanadium nitrides and other nanometer sized particles in the samples that could be responsible for the high hardness values obtained.

1. Introduction

High energy techniques are less expensive processes that open the possibility to obtain products at faster rates and that could be applied for the fabrication of prototypes and short series tooling. Some of these methods as laser sintering described by Simchi et al. (2003) have demonstrated to reduce costs and lead-times required for the tooling phase in production cycles. According to Zhu et al. (2003) there seems to be a promising technique for producing rapid moulds which allows achieving finer microstructures and improving mechanical properties. Furthermore, a number of research groups are currently publishing the results of research related to processing of tool steels and the interactions between process parameters, density and microstructure using high energy techniques. It is the case of Xie et al. (2005) who deals with H13 steel or Asgharzadeh and Simchi (2005) who works with the same system used in this research, M2 high speed steel. The main disadvantages of these processes are their low energy efficiency and the use of sophisticated equipment. In the search for new sintering systems that overcome these issues, the use of concentrated solar energy (CSE) appears to be an interesting technique. CSE is clean, renewable and pollutant free, comes from a natural and inexhaustible energy source and shows a clear activator effect in different processes as demonstrated by Herranz and Rodriguez (2008) in nitriding processes of tool steels in 2008, or surface hardening (Herranz and Rodriguez, 2010). In addition, the cost of installations used for solar energy concentration is not very high. Employing solar furnaces allows materials processing at much higher heating and/or cooling rates resulting in improved mechanical properties and a remarkable reduction on the total cycle time.

In 1969, Kaddou and Abdul-Latif (1969) suggested the use of solar energy for joining metals. However, there are no studies where solar energy is used to sinter metal powders. The introduction of concentrated solar energy in the field of surface treatment of metals has received increasing interest during the last 25 years but only in the last ten has it been applied to the consolidation of parts. Previous researches are focused on studying the viability of the sintering technique for manufacturing ceramic parts using CSE. Thus, Cruz Fernandes et al. (2000) published a preliminary work where high purity alumina powders were compacted and sintered by CSE in inert argon gas atmosphere at 1600 °C during approximately 35 min. The same group, Guerra Rosa et al. (2002), did a similar work using tungsten carbide WC–10 wt%Co applying a treatment no longer than 5 min concluding that solar furnaces can be used for preparation of ceramic materials.

In this way, previous studies have demonstrated the applicability of CSE for sintering process of cordierite-based ceramics (Almeida Costa Oliveira et al., 2005), non-oxide ceramics as Si_3N_4

* Corresponding author at: UCLM-ETSII, Avda. Camilo Jose Cela s/n, 13071 Ciudad Real, Spain. Tel.: +34 926295322; fax: +34 926295361.
E-mail addresses: gemma.herranz@uclm.es, gemma.herranz@gmail.com, ghscosgalla@gmail.com (G. Herranz).

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(Zhilinska et al., 2003) or α-alumina (Roman et al., 2008). In this case the usual intensive grain growth produced by conventional techniques was avoided by using CSE. All previous studies in ceramic materials have proven that the use of CSE leads to parts with better mechanical properties and important reduction in treatment times, but similar works in metallic materials have not been found.

High speed steels (HSSs) are excellent tool, cutting and wear resistant materials due to their high toughness combined with good hot hardness (Hoyle, 1988). Powder processing of these alloys can overcome complicated processes to obtain finished products and offers a cost effective method for producing near net shape components. The complexity of their composition makes them extremely sensitive to sintering parameters. The sintering process has been widely studied and is described using a supersolidus liquid phase sintering (SLPS) mechanism (German, 1990). This process involves heating pre-alloyed powders to an intermediate temperature between the liquidus and solidus, resulting in a partial melting and densification through particle rearrangement and solution-re-precipitation mechanisms. The sintering temperatures and the carbon content are the most important process variables since these determine the volume fraction of liquid phase (Zhang, 1997). Jauregi et al. (1992) demonstrated that the use of a N_2–H_2 gas atmosphere reduces the sintering temperature and improves the microstructure and the mechanical properties of tool parts. In all cases, the HSS sintering takes place in a narrow temperature range (the sintering window). Also, it is well known that the best compromise between toughness and hardness is achieved after applying subsequent heat treatments. However, even finer microstructures have been obtained with faster and more energetically effective field activated sintering techniques for a wide range of metals, ceramics and intermetallics (Groza, 1999). Nevertheless some of these techniques have not yet been explored in the case of HSSs powders. Densification of out-of-equilibrium powders presents challenges related to the specific need to retain the metastability of initial microstructures in addition to usual pore elimination.

This research has assessed the feasibility of using concentrated solar energy (CSE) for sintering-consolidation of green parts previously obtained by compaction of high speed steel metallic powders. The experiments were carried out using two facilities; a solar furnace and a Fresnel lens installation. A detailed study of the microstructure evolution has been made in order to understand the influence of solar sintering in parts' properties and to check the influence of the high energy density on mechanical properties, comparing the solar process with the conventional method.

2. Experimental procedure

The metal powder used in the experiments was water atomized M2 High Speed Steel sold by Höganäs. As shown in Fig. 1, the powder particles are irregular in shape and 80% were below 150 μm. Their chemical composition is given in Table 1.

The samples were cold uniaxially compacted at 650 MPa to fabricate bars (31.6 mm × 12.8 mm × 2.4 mm). Some of the bars were subsequently sintered in a solar furnace at the Plataforma Solar de Almería (PSA-CIEMAT), while others in a Fresnel lens installation located at the ETSII-University of Castilla-La Mancha (UCLM) under the same conditions of N_2–5%H_2 flowing gas at temperatures in the range of 1115–1200 °C. For comparison of the results, the sintering experiments were also carried out in a conventional electric furnace under the same atmosphere and in a temperature range of 1260–1330 °C during 30 min.

The solar furnace consists of a flat 160 m^2 heliostat that follows the sun and reflects the solar beam towards a parabolic concentrator. The maximum concentration at the focal point (23 cm of diameter) is 3000 times the solar radiation. A reactor with a quartz window was placed on the focal area. The tests were done in a horizontal position using a cooled mirror placed along the optical axis of the parabolic concentrator (Fig. 2). The samples were heated up to the sintering temperature at a rate of 50 °C/min, kept for 30 min at the maximum temperature and cooled down under a N_2/H_2 atmosphere at the same speed. Fig. 3 shows a typical heating/cooling curve registered during the experiments.

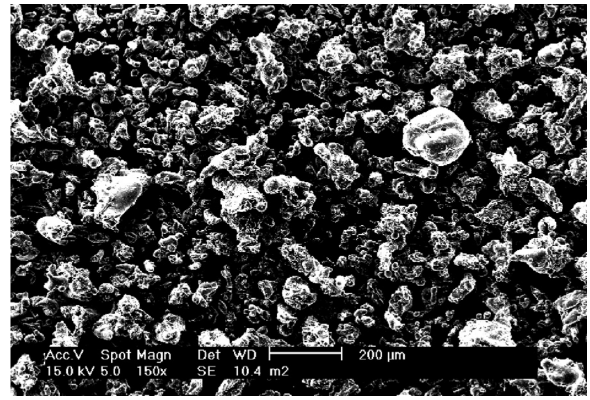

Fig. 1. M2 HSS powder as observed by SEM.

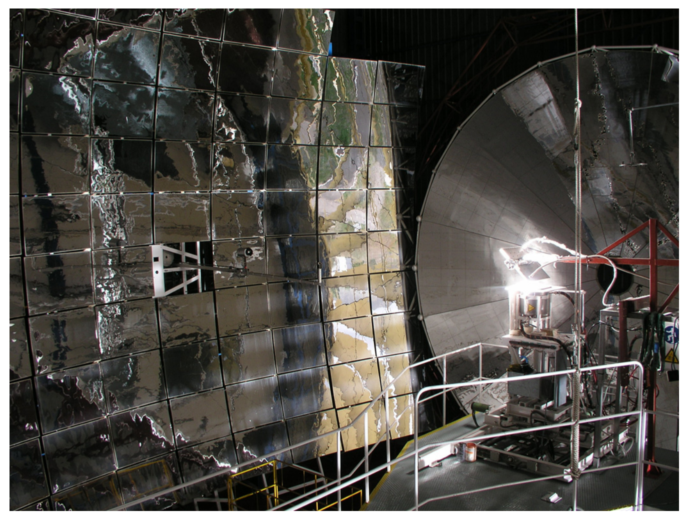

Fig. 2. Solar furnace installation.

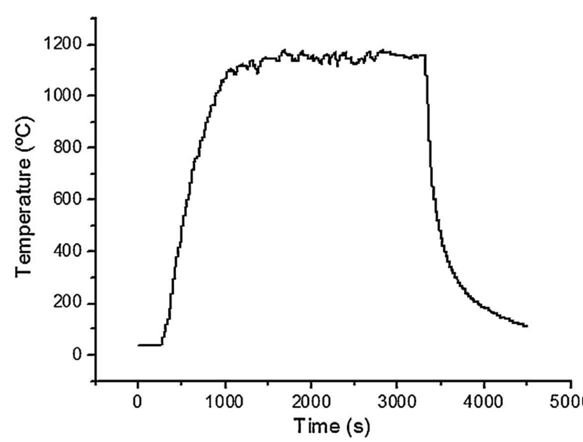

Fig. 3. Typical heating/cooling curves in the solar furnace sintering processing obtained from the thermocouple register.