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Secondary emissions during fiber laser cutting of nuclear material

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ABSTRACT

The laser process has been studied for dismantling work for more than 10 years, however there is almost no data available concerning secondary emissions generated during the process. These emissions are inevitable during the laser cutting process and can have detrimental effects in human health and in the equipment. In terms of safety, for nuclear decommissioning, is crucial to point out ways of controlling the emissions of the process. This paper gives indications about the parameters to be used in order to reduce these secondary emissions and about the influence of these parameters on the particles size distribution. In general, for producing minimal dross and fume emissions the beam focus should be placed on the surface of the material. The higher percentage of secondary emissions which present higher diameter, increases approximately linearly with the stand-off distance and with the use of low air pressure.

1. Introduction

Nowadays an increasing number of reactors has reached the end of their useful life and their safely decommissioning is a topic of public concern. "Time, cost and safety are the key drivers for nuclear decommissioning" (Hilton and Khan, 2014). Laser is a technology that can be used for multiple cutting jobs, which has the potential to reduce cutting times and costs and simultaneously promotes an increase in safety comparatively to other thermal cutting processes.

For the nuclear sector, to ensure a safe operation, it is important to study potential detrimental effects of the technologies used. In the case of welding and cutting, the generation of debris are an inevitable part of the process. When it comes to nuclear decommissioning there is an additional concern, as the material being cut may be radioactive, reason why the minimization of material losses produced by the cut of these materials is of first importance, and has been a matter of study in the recent past (Pilot et al., 2008; Pires et al., 2010; Novick et al., 1996).

Specifically, the aim is to keep the material losses, which represents nuclear waste, as low as possible. Generally, laser cutting produces fewer cutting debris compared with other technologies, due to the smaller kerfs. However, this aspect needs to be analyzed in detail, since to achieve minimum material removal rate.

Various lasers have been used to cut metallic materials for nuclear decommissioning applications, including CO2 lasers, CO lasers, COILs and Nd:YAG lasers. A 5 kW CO2 laser, for instances, has been applied to cut fuel channels (e.g. stainless steel tubes of 95×5 mm size and zirconium tubes of 3 mm wall thickness and 100 mm diameter). Each nuclear reactor has about 1600 fuel channels. In another report, an 8 kW CO2 laser was used to cut stainless steel of 40 mm thickness by incorporating a special high pressure gas nozzle. In fact, laser cutting was found to result in ten-fold decrease in gas and dust contamination compared to traditional methods (Panchenko et al., 2000; Herfurth et al., 1998).

However, the major reason for the limited use of lasers in decommissioning is that historically, industrial lasers have been considered unreliable and not suited to on-site nuclear decommissioning environments. The advent of fiber lasers has provided a more realistic opportunity for use of lasers in decommissioning applications. Nd:YAG lasers operate at 1.06 μm wavelength which enables the laser to be delivered over long distance by optical fibres. The arrival of this lasers has revolutionized the conventional laser cutting process and opened up a new range of opportunities for remote cutting applications, an important characteristic for nuclear decommission.

Previous studies have been carried out to prove the potential of fiber lasers. By comparing the production of secondary laser emissions with the emissions resultant of other cutting tools, laser cutting is the process than produces narrower kerfs, which should lead to smaller volume of fumes and of dross. A study about the secondary emissions during fiber laser cutting (Pilot et al., 2008) shows that the 4 kW laser produces more aerosols than the reciprocating saw but less than the other thermal tools (see Figs. 1 and 2).

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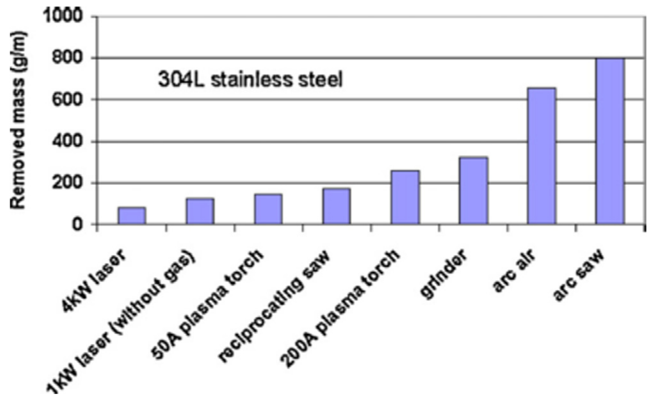

Fig. 1. Comparison of exhausted aerosols produced during the cutting of a 10 mm stainless steel plate by different tools (Pilot et al., 2008).

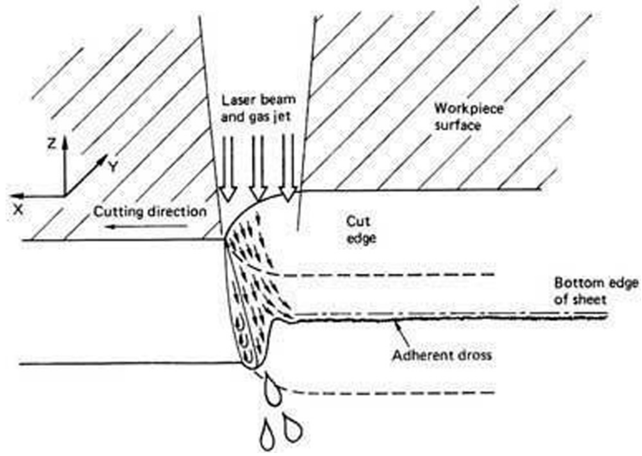

Fig. 2. Laser cutting schematic view (Jüptner, 2002).

The same work points out that the exhausted aerosol mass per cut length (g/m) decreases with the cutting speed and increases with laser power, and varies neither with the stand-off nor with the gas pressure. Also, the amount of these emissions is strongly affected by the nature of the steel (stainless steel or mild steel) and is independent of the plate position. In terms of material removed, there is no obvious influence of stand-off distances and it decreases with gas pressure/flowrate.

Another previous work by Yilbas and Aleem (2006) pointed out that the size of the fumes released has a linear relation with the amount of dross produced. In what regards dross, its formation depends on the laser cutting parameters. The liquid layer thickness increases with the increase of the laser output power, which in turn enhances the droplet diameter, and reduces with increasing assisting air velocity.

Besides existing a significant number of publications related with the potential of fiber lasers and the fumes generation resultant of welding processes there is almost no data available concerning fume and air emissions produced by laser cutting. Also, clarification related with particles size distribution is needed. A review of what concerns laser emissions, as well as its composition and particle size distribution, is presented below. A brief explanation about the concept behind particles size measurements will also be focused.

1.1. Laser emissions

In laser cutting, the secondary emissions are composed of aerosols, sediment dross deposits on the walls of the cell and attached slag (Pilot et al., 2008). Fumes consist of metal oxide particles and gases that are formed from the base material being cut (Jüptner, 2002). These oxide particles are small enough to become airborne being easily inhaled. Dross represents the material removed from the kerf. In this case it is relevant to consider two different types of dross (slag), one is the mass loss in plates and the other the adherent dross on the plates (Hilton and Khan, 2014). It should be noted that the laser emissions are produced mainly on the underside of the plate. As stated above, the control of process, and consequently of the amount, composition and particle size of the fume produced, is of increasing importance in promoting a healthy and safe environment.

The mass removal rate from the kerf is associated with the amount of molten layer produced and ejected. During the laser gas assisted cutting process, the kerf volume is transformed dominantly into the molten state and blown out by an assistant gas. The jet of dross generated consists of metal droplets with different sizes leaving the cutting kerf (Jüptner, 2002) and part of them adheres to the bottom edge of the cut. Depending upon the cutting parameters, the molten layer thickness varies. In order to avoid contaminated waste dispersion, it is desirable that during the cutting process the material removed from the kerf is left attached to the parts being processed (Hilton and Khan, 2014).

1.2. Composition and particle size distribution of laser emissions

Welding fume particles size are among the breathable ones (Pilot et al., 2008), having sizes between 0.1 and 5 μm. It is believed that the airborne micrometer particle's diameter, resulting from the laser cutting process, is directly related to the cut quality, such as the cut edge surface finish, the kerf width, the dross produced and the size of heat affected zone (Yilbas and Aleem, 2006). This means that the control of the process and the particle size distribution of the particles produced can achieve a less hazard process.

In what decommissioning is concern, focus has been paid particularly on particles which are below 10 μm, which is the particles size range that can be inhaled by humans. Thus, the study of the influence of parameters on particles size distribution is crucial in evaluating the use of laser cutting in decommissioning.

1.3. Particles size measurements

Particles are three dimensional objects, and unless they are perfect spheres, they cannot be described by a single dimension such as the radius. In order to simplify the measurement process, the particle size analyzed in this work was defined using the concept of equivalent spheres – illustrated in Fig. 3.

This concept defines the particle size by the diameter of an equivalent sphere having the same property as an actual particle, such as its volume (Overview of Particles and Particle Properties, 2017; Scientific, 2010). Thus, the performed analysis consists of a statistical distribution of particles of different sizes.

In this context, taking into account the hazards associated to contaminated waste dispersion and its size, as well the scarce information available, it is important to understand the influence of cutting parameters on the laser emissions and its particles size distribution.

2. Materials and methods

A set of 30 experiments was performed, for different conditions, to study their influence on the emissions produced during the cutting process. In the present study, the influence of the main parameters referred above was analyzed: material thickness, stand-off distance, laser power and air pressure (see Table 1).