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Review

Application of ultrasonic vibrations in welding and metal processing: A status review

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ABSTRACT

This review paper aims to introduce systematic in-depth analysis of diversified aspects of ultrasonic application in metal joining and processing including its limitations, future prospects and assessments. Allied welding and metal processing technologies employing ultrasonic vibrations either as the primary source to accomplish the intended operation or as an assistant source to improve the operation efficiency and product quality are classified and discussed. The detailed state-of the art, experimentation and progresses of the ultrasonic vibrations and its applications in the above areas are comprehensively examined, evaluated and presented for exhaustive understandings of its physical mechanism. The ultrasonic vibrations assisted processes claim several advantages such as improved mechanical properties, enlarged process window, higher heat generation, better material mixing and enhanced turbulence etc. over the conventional processes which lead to the remarkable and globalized applications of ultrasonic vibrations in the welding and its allied areas in the present century.

Contents

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1. Introduction

Modern era is on the brink of a serious energy crisis because on one hand the non-renewable energy sources are fast draining and on the other hand the renewable energy is still underdeveloped to meet the ever-growing energy demands. At this intricate stage, any action of saving energy is considered valuable from various aspects. Application of ultrasonic vibration has been proving to be indispensable in various diverse areas such as modern medicine and medical diagnostics, chemical and food processing, metal joining and processing etc., even by letting alone the direct service of ultrasound in highly sensitive sectors such as marine, safety and defence sectors. From a materials engineer's perspective, ultrasonic vibrations adds two main advantages to the material processing: lowers the energy consumption and the cost of the process. Ultrasonic application in metal working dates back to the early decades of 20th century. Different manufacturing processes such as machining, forming, joining, etc. are assisted with ultrasonic vibrations to improve the properties of the finished products. These ultrasonic vibrations themselves are the physical vibrations of the molecules in the medium in which the sound is traveling. The frequency range from ∼20 kHz up to several gigahertz is usually termed as ultrasonic range. The effect of ultrasonic vibrations over the metals and alloys are mainly employed for manufacturing purposes. The outcome of ultrasonic integration in metal processing is sufficiently available in the literature [1–12]. Many researchers are exercising on inventing processes to facilitate acoustic softening during material processing. The effect of ultrasonic energy is similar to thermal softening; however, experimental results reveal that the ultrasonic energy required to produce an identical amount of softening is 10^7 times less than the required thermal energy [1,6]. Several researchers in their research work used ultrasonic vibrations for metal working and concluded that it is capable of reducing magnitude of force required to a large extent. Ultrasonic is the preferred method of metalworking in today's competitive world. Ultrasonic claims some advantages over others as follow:

(1) Ultrasonic process is clean, reliable, consistent and affordable.
(2) It needs no pre weld or post weld operations.
(3) It uses no consumables of any nature and is user and environment friendly, rapid and repeatable.
(4) Ultrasonic eliminates subjective elements in the welding process, ensuring consistent quality.
(5) The consumption of energy is perhaps the lowest by any other process [13].
(6) Set up is quick and easy. Its versatility enables change over from one set-up to another within a few minutes.
(7) Tooling has long life, and need little or no maintenance [13].

It is also termed as a green technology owing to the reason that it has an applicability for a wide spectrum of processes without any harm to the environment and human beings. This technology is primarily associated with the usage of high intensity elastic waves which were employed to cause changes in the treated media by the adequate exploitation of the nonlinear phenomena associated to the high amplitudes such as radiation pressure, wave distortion, streaming, and cavitation in liquids and dislocation in solids [14]. This leads to activation of different mechanisms such as agitation, diffusion, interface instabilities, friction reduction, localised heating, and mechanical rupture etc. [14]. As pointed out earlier, ultrasonic vibrations have been applied in various fields ranging from medical diagnostics to chemistry to materials joining and processing. In these different fields, the purpose of ultrasonic application is either primary or secondary. The primary purposes of ultrasonic application involve areas on medical diagnostics, food processing and ultrasonic welding etc. where ultrasonic vibrations play the main role in the process accomplishment. The secondary purposes involve application of ultrasonic vibrations to provide assistance to a desired process to improve the process effectiveness. For instance, ultrasonic application for both primary and secondary purposes has become widespread in various metal working processes. Few papers are available in literature that reviewed the ultrasonic application in machining of metals [15–20]. However, ultrasonic machining (USM) is only a narrow field of manufacturing processes while the ultrasonic vibrations have been widely employed in other areas of metal joining and processing such as in metal forming, fusion welding and solid state welding etc. Therefore, there is an urgent need to compile and critically analyse the state-of-art of the concepts, methods of ultrasonic application, advantages and limitations in various metal joining and other manufacturing processes for quick reference. This paper is an attempt to provide a detailed review that comprehensively covers all the neglected areas of ultrasonic application in the welding and its allied domains.

2. Instrumentation of ultrasonic system

A typical ultrasonic system is a sequential assembly of four major components: generator, transducer, booster, and horn. When integrated to each other, generates and subsequently transfers ultrasonic vibrations to a desired location of metal during a manufacturing process. Conversely, these components are integrated in a predesignated manner to achieve a desired ultrasonic power transfer efficiency. Efficient transfer of ultrasonic power is extremely vital and depends upon the elaborated and in depth design of the ultrasonic components. The design and selection of component materials depend upon the intended area of ultrasonic application. Detailed knowledge of each component is vital for robust designs and desired results.

2.1. Ultrasonic generator

Ultrasonic generator is a solid electronic box which is fed in with 220 V and 50 Hz from the mains as inputs and transforms the input into 800–1000 V and 20 kHz electrical supply. The anatomy of the generator is shown in Fig. 1. The ultrasonic generator majorly constitutes an electronic programmer, protection circuits and a microprocessor. If present, all the above generator parts are housed in a power supply cabinet. Power rating of the generator is based on the area of application and varies from plastic welding to metal welding. Two types of ultrasonic generators are in common use, conventional and automatic. The conventional type requires manual tuning to their dimensions to achieve suitable resonance, while automatic ultrasonic generators (Fig. 2), have an inbuilt system inside which automatically alters the output frequency to match the exact resonant frequency of the horn/tool assembly [21]. Nowadays, ultrasonic generators of frequency 20 kHz are more common in metal processing and welding than 40 kHz. More prominently, generators are designed to operate on a band of specific frequency (19 kHz to 21 kHz) rather than a single band (20 kHz). Digital ultra-