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Comparative Analysis of Friction Stir Welding and Laser Welding

Department of Mechanical and Materials Engineering
Bachelor's thesis

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Various welding processes are used in manufacturing. Most recently invented processes try to improve on aspects such as productivity, and reduced metallurgical changes, and defects. The applicability of a welding process depends on factors such as base material compatibility, required equipment and energy efficiency. The objective of this thesis is to describe the fundamentals of two of the most prominent advanced welding processes, Friction-Stir Welding and Laser Beam Welding. This work is conducted as a literature review. Subjects which are studied of both processes include base materials compatibility, process parameters, energy efficiency, applications, advantages and limitations. Additionally, friction-stir welding is studied by the tools, heat transfer and material flow. For laser beam welding, laser sources and melt pool characteristics are studied. Key differences and similarities are discussed, and a summarizing table of these aspects is presented. In this study it is found that laser beam welding enables high productivity, whereas friction stir welding is limited on the welding speed and flexibility. It is found that, friction stir welding produces good quality welds with various aluminium alloys, whereas laser beam welding is best suited for low carbon steels, magnesium alloys and thermoplastics. Friction stir welding is suggested to be environmentally friendly with no use of consumables.

Key words: Manufacturing, Joining, Friction-Stir Welding, Laser Welding

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1 Introduction

Welding is a manufacturing process for joining materials, which is performed by applying heat, pressure, or both, to the interface of parts to be joined [1]. Many different heating sources and methods for applying pressure in welding have been utilised [1]. Heat sources for welding include combustion of solid and gaseous fuel, electrical arc, laser, electron beam and ultrasound [1]. One aspect for most recent techniques to improve on is reducing the welded area and metallurgical changes in the workpiece material [1]. Welding can be divided into two major categories by the principle of joining used: by melting, and solid-state methods, corresponding to fusion welding and solid-state welding, respectively [1].

Friction Stir Welding (FSW) is a solid-state welding process invented in 1991 [2]. This process has gained interest by industry since it enables welding of materials, which are challenging or impractical to weld by fusion processes, such as aluminium alloys from the 2xxx, 7xxx and 8xxx series [3]. Recent research has been conducted on FSW of superalloys [4], process monitoring via wireless measuring of tool temperature [5] tool eccentricity effect on heat generation and material flow [6].

From 1960 on, lasers have been utilized in material processing [7], and some of its properties such as high energy density and low divergence, make them suitable for welding. According to The European Standard EN 1011-6:2018 [8] Laser Beam Welding (LBW) is a fusion welding process. Furthermore, LBW is categorised as high energy density beam process [9]. Recent research in LBW has advanced to topics such as welding of copper with blue diode adjustable mode lasers [10], modelling melt flow and heat transfer for oscillating beam laser welding [11] and developing hand held laser welding equipment where operator experience does not influence the final product [12].

Laser beam welding and friction stir welding are continuously being improved and developed actively to support new applications. However, some process models utilized for process control still present limitations [13], and many materials in friction-stir welding are yet to be widely implemented such as steel [14].

Therefore the objective of this work is to present the fundamentals of both friction stir welding and laser beam welding, followed by a comparison between these joining processes. This work summarises fundamentals as well as recent advances in these welding processes.

2 Literature review

2.1 Friction-stir welding

Friction-stir welding (FSW) is a material joining process which was invented in 1991 at The Welding Institute (TWI) [2]. FSW is a solid-state welding process as it is conducted at temperatures below melting point of the base metal and without filler material [2].

In the first FSW process, a rotating tool with a probe and shoulder was driven to the interface of two plates to be joined. As the tool rotates, it is simultaneously driven through the workpieces along the interface. The shoulder on the tool is on constant contact with surface of the workpieces, having the friction to heat up the workpiece and to cause severe plastic deformation at proximity of the rotating tool [2,13]. The FSW process is illustrated in figure 1.

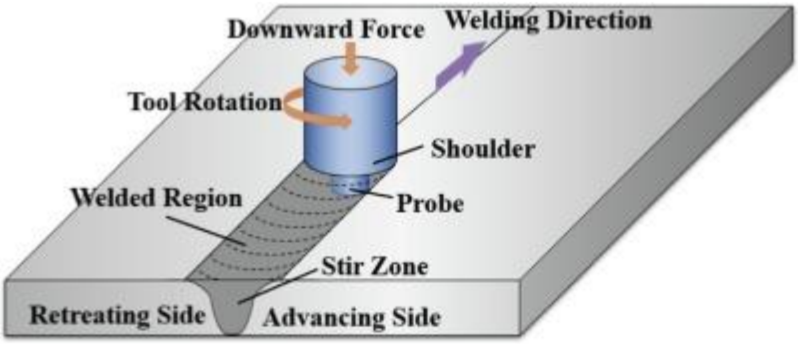

Figure 1. Schematic of basic version of Friction stir welding. Image reproduced with permission from [13]. © 2024 Elsevier Ltd.

2.1.1 Tools

The use of a non-consumable tool is essential for friction-stir welding. Main features of the rotational tool in FSW are shoulder and probe or pin (see Figure 1). The functions of the tool are to heat the workpieces, to move or stir the plasticized material to produce a weld and to control the material under the shoulder [15].

The first and most simple FSW tool is a one-piece tool with probe and shoulder. Various adaptations to the first FSW tool concept have been made [13]. These include adjustable length probes, self-reacting tools, stationary shoulders, reverse rotating shoulders and stationary shoulders with filler wire input to name a few [13,16]. Figure 2 shows the adjustable length, and the self-reacting or bobbin type tool configurations.

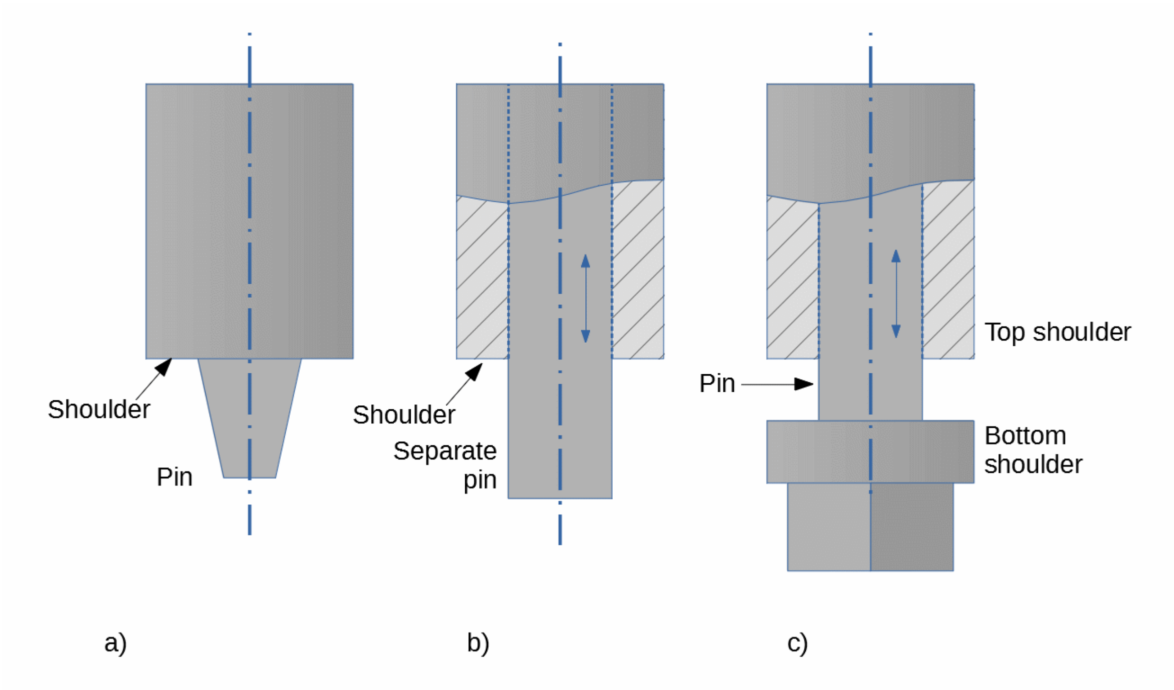

Figure 2. Schematic of FSW tool configurations: a) fixed b) adjustable c) bobbin

The basic FSW tools can be improved by geometrical modifications. With flat shoulder the plasticized material is susceptible to expulsion, and this makes forming of flash defect likely. Scroll and other shoulder features are recommended for the containment of material. The scroll feature is shown in figure 3. These also increase the friction, intermixing, shearing and deformation at the weld. Another approach to the material expulsion and flash problem is the concave shoulder. With concave shoulder the material is effectively contained around the pin. FSW tools with concave shoulder are widely used in industry, because this feature is more simple to machine than complex geometries such as scrolls [16]. Figure 4 shows the concave shoulder as well as the flat and convex shoulders.

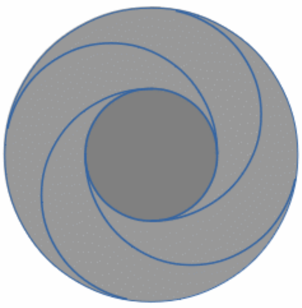

Figure 3. Schematic end view of FSW tool scrolled shoulder

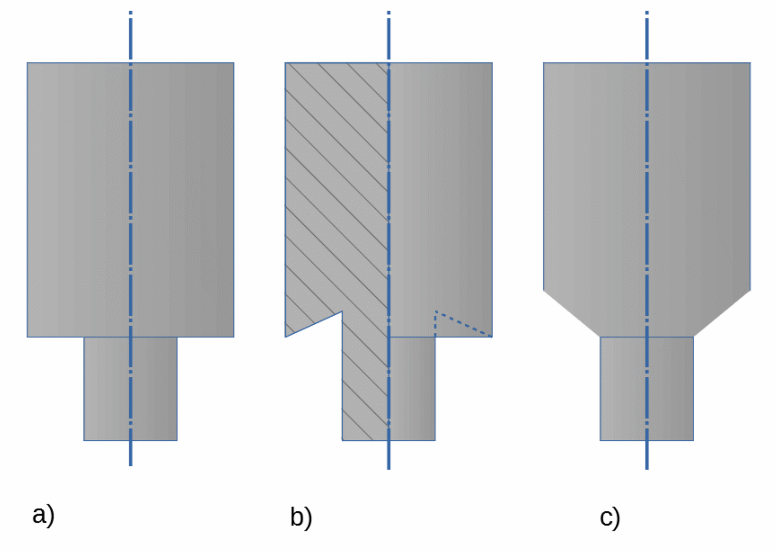

Figure 4. Schematic of FSW tool shoulders: a) flat b) concave c) convex

Convex tool (see Fig. 4c) shoulder provides an advantage which does not apply to flat nor concave shoulder. Convex shoulder can be used with various plunge depths. However, convex shoulder has inferior containment of plasticized material. Therefore, scrolls and other such features are recommended [16].

In addition to tool shoulder geometry the pin geometry is similarly important. The pin can create deformational and frictional heat as well as shear the material in its front and move this behind the tool [15]. Various features such as threads, tapers, flats and flutes are applied and combined for adjusting the heat and material flow. Some of the various tool pin geometrical features are shown in figure 5.

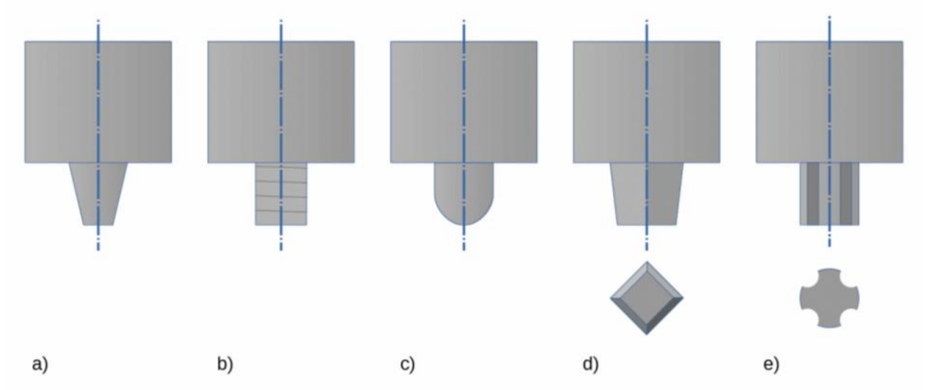

Figure 5. Various FSW tool pin geometrical features: a) conical b) threaded cylindrical c) domed end d) tapered with flats e) fluted

Threads are applied for increased flow downwards, away from the shoulder [15]. Left hand threads are commonly used when the tool is rotating clockwise. Threadless probes are useful in welding high strength or highly abrasive materials, in which threads could be worn or fractured easily [15].

Flat-end feature in FSW tools leads to higher plunging force compared to a domed-end tool such as in (see Fig. 5c) [16]. However, a dome with smaller radius often leads to reduced stirring action at the tip of the pin [15,16].

Important properties for FSW tool include strength, fatigue and fracture toughness, wear resistance, thermal conductivity and coefficient of thermal expansion [14,17]. According to Rajak et. al [17], the selection of the tool material considers the tool wear and required weld quality, therefore, it also depends on the workpiece material. For working high temperature softening alloys, such as various carbon and stainless steels, the tool material must meet demanding requirements in temperature over 900 °C. Tool material should have high strength, fatigue and fracture toughness and resistance to chemical and mechanical wear at high temperature [14]. Recommended materials for working with steels are Poly crystalline Cubic Boron Nitride (PCBN) and refractory metals such as tungsten, molybdenum and tungsten-rhenium. However, both PCBN and refractory metal tools have limitations, and the tendency for fracture has been reported for both materials, especially with high forces associated with plunging operation [14].

2.1.2 Base materials

Many materials have been experimented for friction stir welding. Materials which have received attention include aluminium alloys, Ti-alloys, Cu-alloys, Mg-alloys and various steels [13]. Most of research has been conducted to optimize FSW for aluminium alloys [18] because most of the industrial applications of FSW are suitable for these materials. FSW of Al-alloys has been successfully applied in various industries such as aerospace, offshore, railways and automotive [14]. Additionally, welding of thermoplastic materials has been researched [19].

Interest has been shown also to FSW of superalloys such as Inconel 600, 625 and 718 and Haynes 282. Fusion welding of superalloys is more susceptible to defects such as solidification cracking and micro segregation. FSW, as a solid state and low heat input process, has the prospect to mitigate the shortcomings of fusion welding [4,20]. The current main concern is the high temperature, forces and tool wear associated with FSW of superalloys, which commonly have high temperature strength. Special techniques of argon shielding, water cooling low speed and a novel hemispherical tool have been proposed to make FSW of superalloys feasible in industrial setups [4].

FSW research of thermoplastics was initially conducted with conventional FSW tools. Similar tools were used as in welding of metallic materials. Promising joining efficiencies have been discovered with conventional tools, but problems with material ejection by the rotating shoulder have been reported [19]. Some methods, such as stationary shoulder, double step shoulder and concave shoulder profile, have been developed to mitigate the problem [19].

2.1.3 Heat and material flow

FSW produces a weld with distinct zones of different microstructures than those from Base Material (BM). Weld has three distinct zones, which are: i) Nugget Zone (NZ), ii) Thermo-Mechanically Affected Zone (TMAZ), and iii) Heat Affected Zone (HAZ) [2,21]. Nugget zone is also known as stir zone, where material goes through intense plastic deformation and heating, and is characterised by a fine grained microstructure [2]. At TMAZ the microstructure appears to be plastically deformed, but not recrystallized [2]. At the HAZ, no mechanical deformation occurs, although the material is affected by the heat input [2,21]. Figure 6 shows these zones in reference to the tool shoulder.

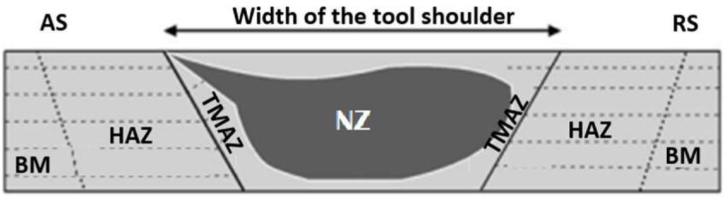

Figure 6. Schematic of different zones of Friction-Stir Weld. Reproduced with permission from [21] © 2022 Prabhakar et. al.

In solid-state welding processes the number of unwanted properties and defects that are typical to fusion welding can be mitigated. Fusion welding processes are essentially local casting processes as material is brought to liquid state and let to cool down and solidify. Welds made with fusion welding can have decreased ultimate tensile strength, fatigue strength and increased ductility [18]. These welds suffer also from oxidation, porosity, hot cracking and micro-segregation[18]. FSW, as a solid-state welding process, can decrease these effects, once it does not involve melting and the temperatures are generally lower than in fusion welding [18]. In FSW of Aluminium Alloy AA6082-T6 (melting point 580°C) the peak temperatures at the stir zone varies between 400-540 °C [22]. Similar temperature differences between peak temperatures and melting points have been determined also for other aluminium alloys [22].

Material flow and its effects such as periodic patterns and onion rings feature are characteristic to FSW. Material flow phenomena in FSW are not fully understood [13]. Material flow during FSW is difficult to observe directly [13]. Rotating tool can be stopped rapidly during welding and signs of material flow in the workpiece can be examined. Material flow in FSW has been studied with 3D-modelling and computational analysis [6,13].

Welds produced by FSW show periodic patterns at the surface of the weld. The surface patterns are shown in fig. 2. It has been found that spacing of periodic patterns is the same distance as the tool is advanced in a rotation. Furthermore, it has been indicated that pattern is created by the tool geometry. Even in rotationally symmetrical tools there is some amount of inevitable runout. With 3D-modelling it has been determined that heat effects caused by the tool’s eccentricity are insignificant. On the contrary, material flow direction and velocity are significantly affected by the tool eccentricity. This can be supposed as the primary cause for periodic patterns and onion ring formation in the cross-section [6]. Ring pattern in the cross-section of weld which is called onion ring pattern is shown in figure 7.

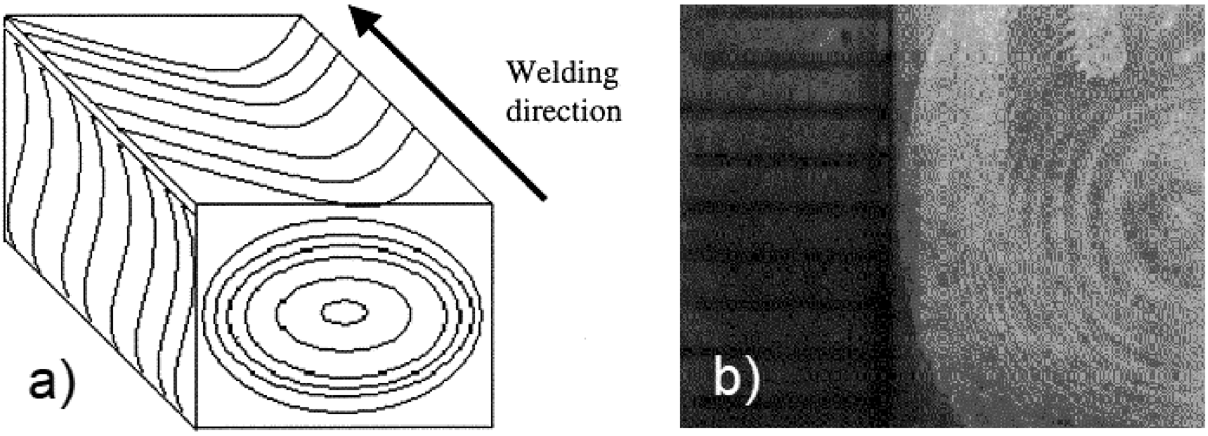

Figure 7. **a)** Schematic of various structural features of FSW and **b)** picture of cross section showing onion ring phenomenon. Adapted with permission from [23] © 2002 Elsevier Science B.V.

2.1.4 Process parameters

Significant process parameters for friction-stir welding include tool rotation speed, translation speed, plunge depth and tilt angle. Choice of parameters determines the generation of heat and material flow [16]. Furthermore, the tool features have additional effects on the heat and material flow. Tools effect on the process is discussed in section 2.1.1. Process parameters are categorized by parts of equipment as shown in figure 8.

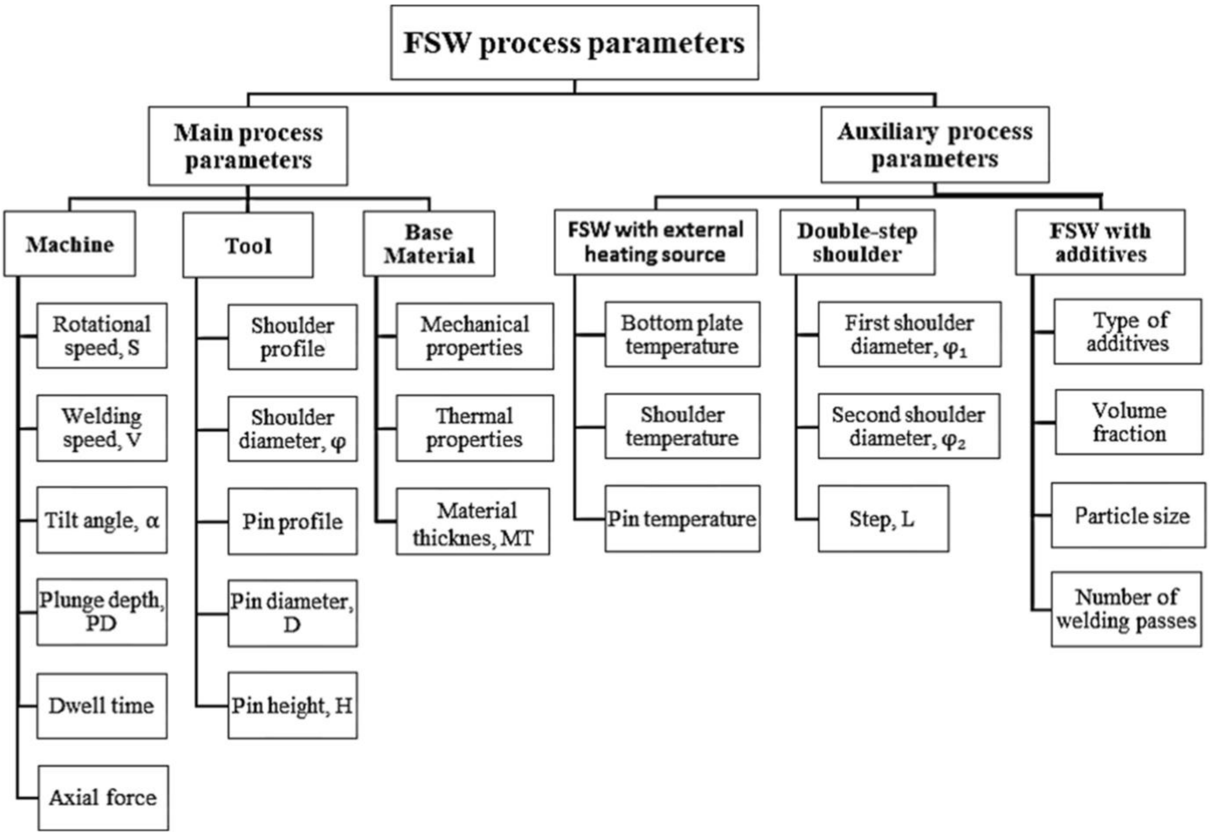

Figure 8. Friction-stir Welding process parameters. Adapted with permission from [19]. © International Institute of Welding 2021

Tool rotation speed affects the frictional heat generation. Increasing tool rotation speed leads to increased temperatures in nugget zone, HAZ and base materials. Low speed results in inadequate heat to plasticize the material and consequently to defects and low strength of weld [16].

Tool translation speed sets the distribution of the frictional heat generated by tool rotation. The translation and rotational speeds collectively determine the quality of weld. When tool translation speed is increased the heat over unit length of workpiece becomes lower.

Insufficient heating of the material causes difficulty in material flow, increased torque and tool wear or breakage. Deficiency of plasticization leads to an elongated void in the weld, which is known as tunnelling defect [16].

Tool plunge depth, which is determined by the axial force or vice versa, influences pressure, temperature and material flow in the process [16]. Additionally, axial force affects the grain size in the weld, hardness of the stir zone and formation of defects [17].

2.1.5 Energy efficiency

The energy efficiency of FSW is influenced by the distribution of energy into different losses and actual welding. Losses of energy in FSW include the machine and dissipated heat through the workpiece, tool and work holding device. The use of energy in different parts of FSW process is shown in figure 9. In a conventional FSW setup for welding of a 5 mm AA7075 plate the energy efficiency of 25 % could be achieved without accounting losses by the FSW machine [24]. Most energy is lost at the anvil plate by thermal conduction, which can represent as much as 62 % from the FSW energy input [24].

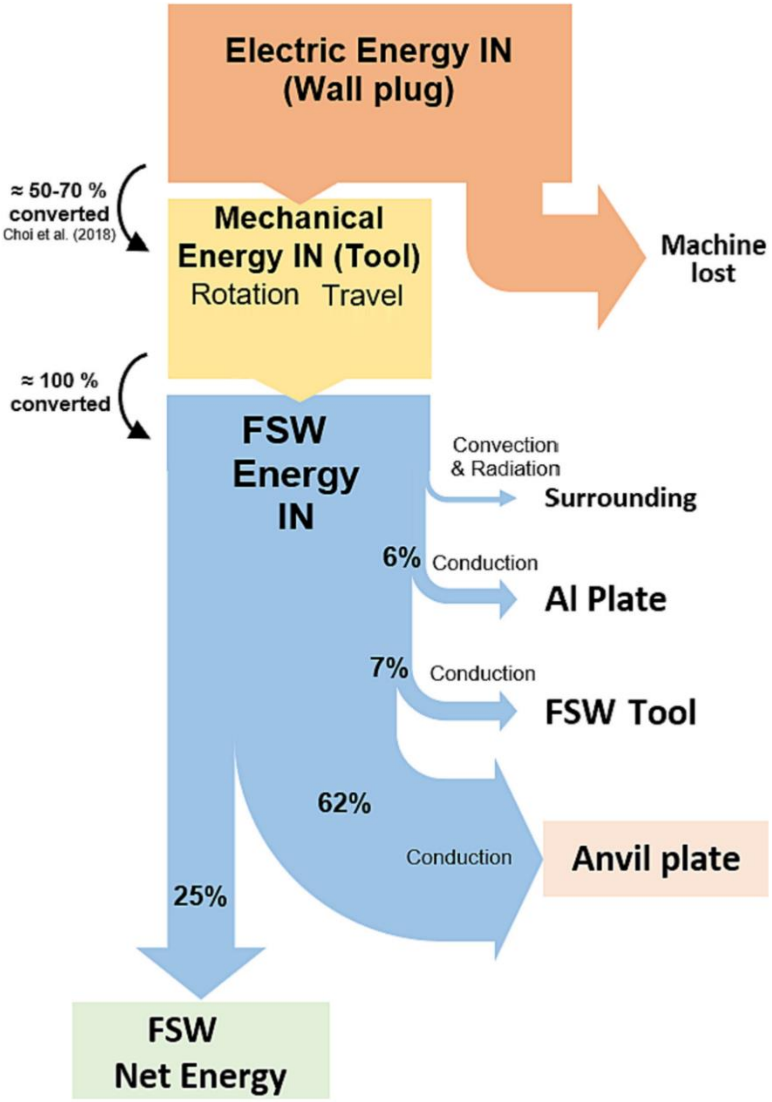

Figure 9. Friction Stir Welding of AA7075-T651: Energy Distribution. Modified from [24] © 2023 Inácio et. al.

2.1.6 Applications

Friction-stir welding has found its way to many different fields including automotive, aerospace, marine, railway, nuclear energy, food and medical industries [25–28]. The reasons for using FSW in these fields are related to the material selection, defect free weld surfaces, capability to weld dissimilar materials, deep weld penetration and good electrical properties among other things [26].

In automotive industry FSW can be applied to include tailored blank manufacturing, wheel rims, thin walled profiles and heat sinks for electric vehicles [26,28]. FSW has been stated to be particularly suitable for welding heat sinks for electric vehicles [26]. In these assemblies a casted and a sheet metal part are welded together. While the casting can have unavoidable pores, the tightness of the welded joint is not affected by the pores. In tailored blank manufacturing FSW is versatile process as it can even be used to join plates of different thicknesses. Additionally, FSW joints have the capability to be formed directly without requiring reworking of the welds [26].

FSW is applied in aerospace industry to produce various components. Conventionally riveting is often chosen as the joining process for manufacturing of aeroplane components. Riveting has the disadvantage of being time-consuming. Interest to replace riveting with FSW in aerospace industry is high [28]. First commercial aircraft to use FSW on the primary structure was the Eclipse 500. Eclipse Aerospace claims that FSW is approximately 10 times faster than riveting [29].

In food industry FSW joints are hygienic as the weld surfaces are defect, pore and gap free. A special case of FSW for food industry is the production of trays for freeze-drying [26].

Friction-stir welding can be used in sealing nuclear waste capsules made of copper [27]. The penetration requirement of the weld is high in this application as the wall thickness of the capsules is 50 mm. Additionally, weld quality requirements are high. For example oxidation must be avoided and therefore inert shielding gas is used in the welding process [27].

2.1.7 Advantages and limitations

FSW possesses significant differences over conventional and modern fusion welding processes. Some of its advantages, when compared to fusion welding are: overall better mechanical properties, corrosion resistance, no need for shielding gas and no production of fumes, such as carbon monoxide, during the process [30].

On the other hand, FSW leaves an exit hole to the workpiece, after the tool is withdrawn and requires heavy duty clamping system [2].

2.2 Laser welding

Laser welding (LW) or laser beam welding (LBW) is a fusion welding process. The power source, laser is based on light amplification by stimulated emission of radiation. Laser beam is directed where workpieces are to be melted. Laser welding is often performed in keyhole mode, where a deep cavity is created by vaporizing material with high power density [8]. Figure 10 shows a general butt joint LBW arrangement.

With comparison to arc welding, laser welding is versatile, economical and reliable method for most materials. The heat input to the workpiece can be precisely controlled and the heat affected zone (HAZ) can be kept small [31].

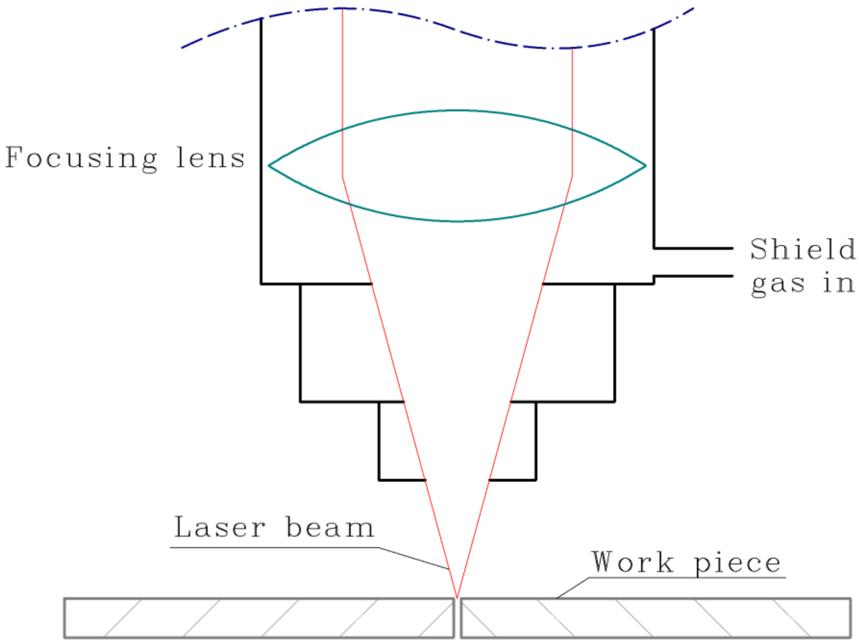

Figure 10. Schematic of general Laser Beam Welding configuration

2.2.1 Laser characteristics

There are many types of laser sources, and the laser can be transferred to the workpiece by different ways. Common laser sources for welding include: CO_2, Neodymium doped aluminium yttrium garnet (Nd:YAG), fibre, disk and diode [9].

The configurations to deliver the laser beam to workpiece often consist of reflective and transmissive optics, such as mirrors and lenses. Optic fibres are also used. However, these are not suitable, when using a CO_2 laser, because the long 10.6 µm wavelength is absorbed by the fibre. Optical fibres provide a practical means of beam delivery for applications such as numerically controlled welding machines and robotic welding [9].

One difference between different laser sources is their typical beam quality. This can be expressed with Beam Parameter Product (BPP), which is the product of the half beam divergence angle and the focused radius, and which value is low when the beam quality is high [32]. Disk and fibre lasers have high beam quality, with BPP under 10 mm mrad [33]. For high quality beam the amount of diffraction is small, thus allowing focusing the beam to a small spot [32]. Therefore, a high energy density can be produced, which allows deeper penetration or higher welding speed. Additionally, increasing beam quality allows usage of smaller and lighter focusing optics if spot size stays constant [32]. Light optics leads to easier handling of robot.

Power distributions of the laser beam can be specified into single-, ring-, donut- and multi-mode [32]. Altering the power distribution is known as beam shaping. Single mode lasers produce a gaussian distribution of power. Other power distributions have been produced such as that of ring- or dual-mode laser, where beam is focused into a core and surrounding ring. Figure 11 shows single-mode and dual-mode laser beams.

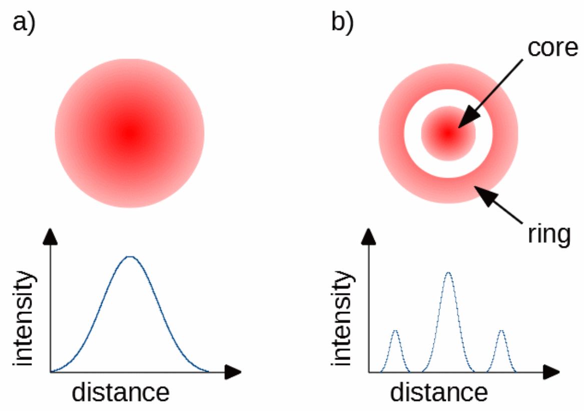

Figure 11. Laser beam power distribution a) single-mode b) dual-mode

Laser operation has two modes: Continuous Wave (CW) and Pulsed Wave (PW). PW offers distinct possibilities and advantages such as improvement of penetration, better welding of a reflective material, better control over the flow in the melt pool and reduction of spattering and porosity [34].

2.2.2 Base materials

Material properties which affect the laser weldability of a material include thermal conductivity and reflectivity [32]. Challenges may arise with crack sensitivity with materials like aluminium alloys, fully austenitic stainless steel and Ni-superalloys [32]. Porosity may occur with materials susceptible to volatilization, with chemical reaction occurring in the melt pool or with metals that have high dissolved gas content [34]. Suitable materials for laser welding include various steels with low carbon, magnesium alloys and thermoplastics. Special procedures, such as rotating or wobbling beam focal point and using pulsed wave, are needed to weld aluminium alloys and copper [32].

2.2.3 Process parameters

Parameters which determine the weld penetration include laser power, power density, laser wavelength, welding speed and parameters related to the gas shielding. Relevant parameters of gas shielding are the gas used, its flow rate and gas shielding method [32]. Beam power and beam diameter are often analysed together as these determine the power density, and the penetration of keyhole-mode LBW increases nearly linearly with respect to the power density [9].

The formation of defects often limits the workable welding speed. Humping defect can occur when welding speed is increased above a certain point [35]. This particular defect can be defined as a severe undulation at the top of the weld along the welding direction. Another defect that tends to occur at high welding speed is undercutting, which is also regards as pre-humping in the context of LBW [36]. Despite the limitations caused by humping, high welding speed can be achieved with LBW. Welding speed up to 12 m/min was used with no humping nor undercutting occurring when welding SUS304 austenitic stainless steel with laser power of 6 kW and 9 kW [35].

Beam shaping is seen as a promising parameter for improving melt pool and capillary dynamics [10]. Altered power distribution of the beam can reduce the surface roughness of the weld and voids in the weld [37]. Adjustable ring mode lasers have shown their benefits, especially reducing spattering, for welding of copper and aluminium alloys, stainless steel and other materials [32].

2.2.4 Melt pool characteristics

With high enough power density, a hole is melted and evaporated to the base material, generating the keyhole. The keyhole’s characteristic shape and flow of molten material is illustrated in figure 12. The keyhole is stabilized by the pressure of vapour being created [34]. The ratio between fusion-zone height and width is known as aspect ratio. Keyhole-mode welding results typically in a high aspect ratio, usually up to 25 [9].

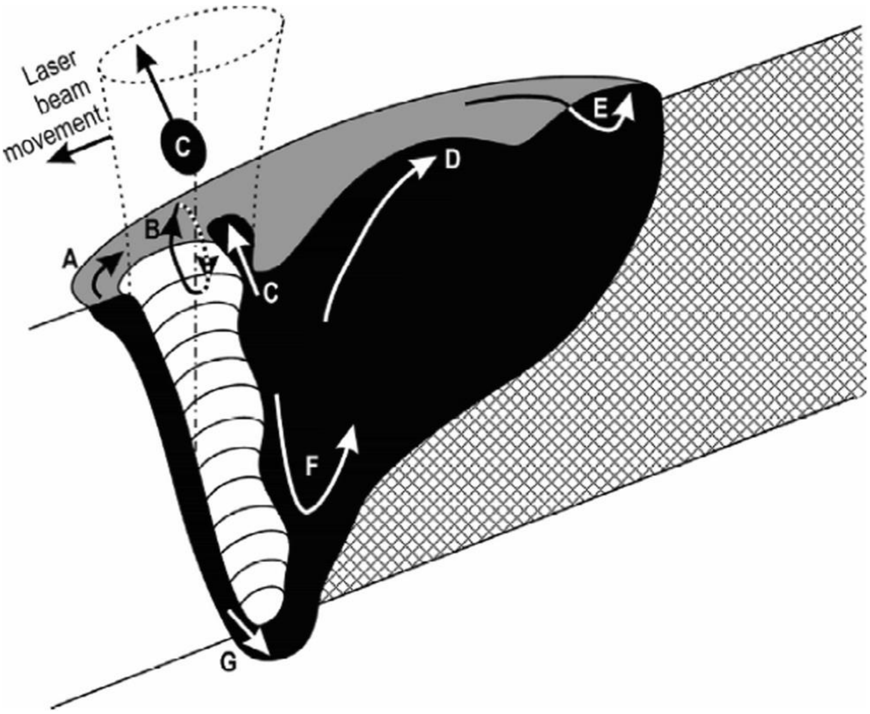

Figure 12. Schematic of keyhole and melt flow phenomena: Melt flow around keyhole (A), Marangoni flow (B), spatter generation (C), humping (D), rear flow (E), eddies (F), and root drop-out (G) Reproduced with permission from [38] © 2009 Canopus Academic Publishing Limited

Another mode for laser welding is the conduction mode, in which lower power density or lower irradiation time, such from a pulsed wave is used. The fusion zone in conduction mode is different from keyhole mode welding, and the aspect ratio is typically lower than 1. Furthermore, transition modes between conduction and keyhole modes exist [9].

The laser beam absorption to workpiece is called coupling. The beam coupling depends on workpiece reflectivity, wavelength of laser and effects of vapor plume being created [9].

Shiny metal surfaces at room temperature typically show high reflectivity to laser beam, leading to a higher energy dissipation through reflection, with more reflective materials. With a combination of reflective alloy, such as aluminium, and suboptimal wavelength of CO_2-laser, the energy absorption through the welding can be as low as 1% [9].

Reflectivity is effectively almost removed with the keyhole formation. When laser beam enters the keyhole, it is reflected multiple times inside the hole before exiting. Nearly all of the beam power is absorbed [34]. Absorption efficiencies of 75–90 % have been reported for keyhole mode LBW [9].

Sudden change of beam coupling associated with transfer from conduction mode to keyhole mode can have adverse effects. High power density is required to create a keyhole and subsequently absorption efficiency becomes high. This can lead to damage to the weld structure [34].

Vapour plume is created in high penetration welding as workpieces are vaporized. Vapour plume can also cause problems when interacting with the laser beam. Problems arise from the absorption, scattering of the laser beam. Then the energy transferred to the workpiece becomes fluctuated and consequently the penetration depth varies [9].

Fluid flow in melt pool can have effect on the result of weld. Although no external stirring is conducted the molten base material and vapour are excited to flow in the melt pool. Main contributors to the flow of molten material are the pressure of the vapour plume, temperature-dependent surface tension forces and buoyancy [9,34].

In LBW three distinct regions are found in the weld besides the base material (BM). These regions are Fusion Zone (FZ), Partially Melted Zone (PMZ) and Heat Affected Zone (HAZ) [39]. The distinct zones and their usual microstructure is depicted in figure 13.

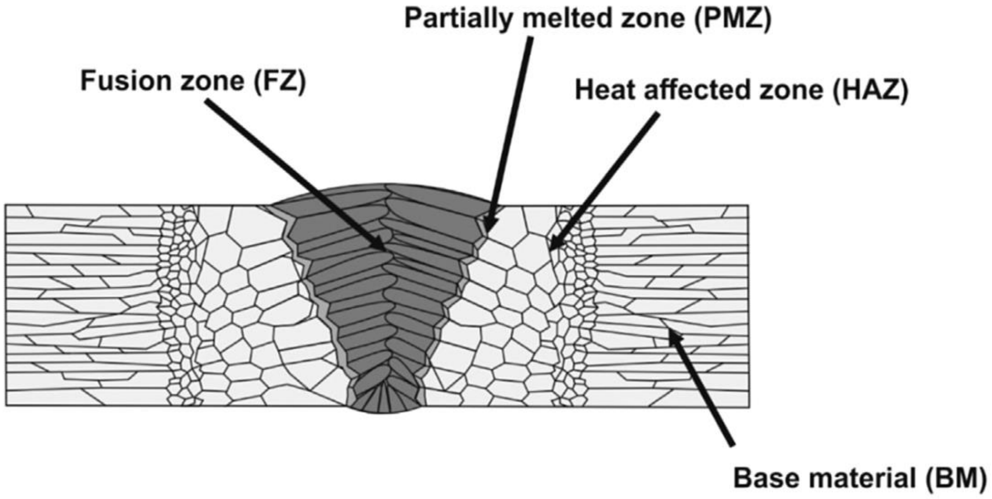

Figure 13. Schematic of regions in Laser Beam Weld. Image reproduced with permission from [39] © 2021 Elsevier Inc.

2.2.5 Energy efficiency

The energy efficiency in LBW is determined by the losses compared to the melting of the workpiece material. Energy losses in LBW include inefficiency of laser source, reflection at the workpiece and inefficiency at melting the workpiece [9]. Laser sources have efficiencies ranging from 0.1 to 73 % where lamp pumped YAG has the lowest and diode laser the highest efficiency [9]. Disk and diode lasers have also relatively good efficiency, reported up to 60 % [9].

2.2.6 Applications

Lasers offer a high flexibility in terms of processes and applications, since light can be delivered through a combination of transmissive and reflective optics to the workpiece. Some of the applications are welding from inside a pipe [34], remote welding with scanning optics [32] and handheld laser welding [12].

In automotive industry laser welding is used widely. One process where LBW is utilized all over the world is the manufacturing of tailored blanks. These large blank plates in tailored blank process are welded from two or multiple sheets of different shapes, thicknesses and materials. Tailored blanks are pressed into shape, such as car doors and body parts, after welding. Tailored blank process is diverse and expanding as it has capability to arrange different sheets optimally and reduce number of parts [32].

In railway industry, resistance spot welding was used conventionally to manufacture bodies of railway vehicles from stainless steel. However, the resistance welding has disadvantages such as distortion to workpieces and compromised aesthetics. Therefore, LBW has been applied from inside of the railway car with moving focusing head and rolling pressing jig to produce partial penetration lap welds [32]. These welds exhibit small distortion and hardly any traces outside the car.

2.2.7 Advantages and limitations

The main advantages of laser welding are the deep penetration and high welding speed [9]. These advantages improve substantially the productivity of the process even with thick section components. Other advantages which have been recognised for LBW include narrow HAZ, low distortion, low level of residual stress and fine microstructure with respect to conventional fusion welding [39].

Laser welding can be performed with high travel speed. Speeds on order of some meters per minute can be achieved with moderate penetration of less than 10 mm [9].

Usually, the downside most of laser processes is the operator hazard, which can involve eye damage, skin damage, electrical hazards and fumes [34]. Different wavelengths are absorbed in different parts of the eye. Wavelengths at or near the visible spectrum are most dangerous as those are transmitted through ocular fluid and can consequently cause damage to retina [34].

3 Discussion

The key differences and similarities of LBW and FSW processes based on the literature review are described in table 1. The points in the table are chosen on the topics which were discussed in the literature review.

Table 1. Key aspects of Laser Beam Welding and Friction-stir Welding

Process	**Laser Beam Welding**	**Friction-Stir Welding**
Principle	Fusion Welding	Solid state welding
Key equipment	Laser	Rotating tool
Heat source	Absorption of light	Friction and material deformation
Temperature	Above melting point	Below melting point
Heat affected zone	Narrow	Extends besides shoulder trajectory
Filler material	Not necessary	Not necessary
Shield gas	Required	Not required
Speed	High	Moderate
Usual defects	Porosity, Humping, Spattering, Micro segregation, Cracking	Flashing, Hooking, Tunneling defect
Operator hazards	Eye damage, Fumes, Hot workpiece	Hot workpiece

The two first rows of the table describe the principles of the LBW and FSW processes. High energy density laser beam is used to perform fusion welding in LBW. On the other hand, rotating tool is used in FSW to perform solid state welding.

The phenomenon which causes workpiece to heat up is described as heat source in the table. In the LBW this is mainly the absorption of light at the workpiece. With the FSW process phenomena which cause heating are the friction between the probe or the shoulder and the workpiece along with the workpiece material deformation

The temperature of the two processes in the weld is different and is stated in the table as temperature. As LBW is a fusion welding process it is performed above the melting point of the workpiece material. On the other hand, FSW is generally performed below the melting point of the workpiece material, but exceptions to this are possible. With some workpiece materials melting can occur.

While many adaptations with filler material to both the LBW and the FSW processes are introduced the most basic processes do not require any filler material.

The shield gas requirement between the two welding processes is different as is stated in the table 1. In the LBW inert shielding gas is needed to prevent oxidation of the workpiece material. Additionally, the gas is used to blow the plume away from the laser beam.

In LBW defects such as porosity, humping, spattering, micro segregation and cracking can occur. In FSW usual defects are different from those in LBW and fusion welding in general. Usual defects include flashing, hooking and tunnelling defect.

Due to the process physical principle, in LBW, more caution must be taken by the operator. Lasers can cause eye damage and therefore welding equipment must be confined adequately or personal safety equipment must be used. In both processes burns may be caused by hot workpiece, if adequate gloves are not used.

Besides the key points discussed in the table 1, further comparison can be made on the flexibility or any other miscellaneous advantages of the two welding processes. LBW offers high flexibility whereas with FSW the work holding requirements and specific tools for different applications decrease the flexibility. LBW can be even used in portable applications with by the handheld laser welding and FSW has the advantage of unique microstructure and weld quality.

4 Conclusions

In this work, the fundamentals of friction stir welding and laser welding processes were studied. Particular attention was given to the applicability of both joining techniques across materials, energy efficiency, and industrial contexts. Some of the outcomes are listed below:

- Base materials weldability was studied for each given processes, with a focus on how specific process parameters influence the final weld properties.
- The analysis covered energy efficiency, main advantages and limitations for the processes, and significant or otherwise unique applications.
- For FSW, critical aspects such as tools design, heat and material flow behaviour were described.
- For LBW, this study explored laser sources and melt pool characteristics, providing insight into the thermal and metallurgical dynamics.
- Recent developments and variations of the processes were also reviewed, and the key comparative analysis of the FSW and LBW was summarized and presented in a table supported by the discussion on the different operational, mechanical and practical aspects of the processes.

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