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Procedia CIRP 3 (2012) 614 – 619

www.elsevier.com/locate/procedia

45th CIRP Conference on Manufacturing Systems 2012

Forming Process Integrated Induction Brazing

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Abstract

Processing steps additional to forming operations, such as joining, usually require a vast effort for transport and storage. Due to integration of currently external production steps, processes could be synchronized. Brazing represents an additional operation, which is likely to gain of importance in the light of an increasing relevance of light weight construction. Servo presses enable an adjustment of the ram motion to process requirements. Hence, the ram motion can be adjusted to create a time slot for the execution of additional processes inside the press. In this paper, the possibility to integrate brazing into forming process chains is investigated. For a demonstration part, a tool that allows brazing inside a servo press is developed. Achievable part qualities and cycle times are evaluated.

Keywords: Forming; Process Integration; Brazing; Servo Press

1. Introduction

Forming processes are characterized by a very high degree of specialisation, productivity, and optimisation. However, a challenge occurs from the development of process chains that include processing steps additional to the forming operations. Hence, process chains are often not synchronized and the productivity gains provided by forming operations are often wasted by a suboptimal design of the process chain.

By integration of external production steps, such as joining, assembly or varnishing operations production processes are synchronized. Hence, storage and transport costs can be minimized. A joining operation inside a forming die allows a highly accurate positioning of the parts, while the die provides a very high stiffness [1]. Further, process integration allows conducting the joining process at the optimal position within a progressive die. Thus, the accessibility of the joint area can be assured while increasing imprecisions resulting from forming operations subsequent to the joining operation can be minimized.

Hitherto, process integration is not widespread. Integrated laser welding processes come into operation for very small parts, especially for the punch bundling of electronic components [2]. Further, the integration of stud welding has been investigated [3]. These operations are conducted on conventional presses.

With the ongoing development of servo press technology new possibilities for process integration arise. While for conventional mechanical presses the ram movement is determined by the rotary cam, servo presses offer the possibility to almost freely adapt the ram movement. This allows creating a time frame for the execution of additional processes inside the press by holding the ram in an arbitrary position [4].

The potential offered by servo presses with regard to process integration has been investigated by Schuler AG, which developed an integrated capacitor discharge welding process for the joining of welding nuts. Herewith, the parts' accuracy could be increased while the process chain was reduced by an external welding station as well as by the according palletising and transport times [5].

With a steadily increasing relevance of light weight construction brazing is gaining importance. It allows the production of areal high strength connections. Thus,

doi:10.1016/j.procir.2012.07.105

stress peaks in the joining area can be avoided. Further, the joining of multiple material combinations can be realised by brazing allowing a load adjusted part design.
Due to the required minimum process time the integration of brazing has not been possible employing conventional press technology. Using servo press technology however the time frame necessary for the integration of brazing can be provided. Hence, this paper investigates the possibility to perform brazing process in a servo press.

2. Conceptual Process Design

In brazing the solder is usually drawn into the brazing fit by capillary forces. Hence, the geometry of the brazing fit represents a critical process parameter. For a too wide fit the capillary forces are not sufficient while for a too small fit the emergence of crystals is hindered since the dimension of the emerging crystals is greater than the capillary [6]. Further, the fit may not be sufficiently wide to ensure the appearance of enough brazing flux [7]. The design of a brazing fit should ensure either a parallel or narrowing fit geometry in direction of the solder flow [8]. Further, a diffusion process is crucial for the brazing joint's strength. It takes place between the liquefied solder and the base materials, resulting in an alloy zone containing elements from the base material as well as from the solder. The size of the diffusion zone and thus the quality of the joint essentially depends on the difference in the working temperature of the solder and the solidus temperature of the base materials, the chemical similarity of solder and base materials and the heating profile. As an approximate value the heating should be maintained for three to four seconds after the solder stopped flowing to achieve a good quality of the diffusion zone [9].

2.1. Process categorisation

Integrated joining operations can be classified according to three essential criteria. With regard to the position inside a progressive die the joining operation can be executed in a separate die station solely for the joining operation or inside a die station that also executes a forming operation. As a modular solution the separate joining station favours the possibility to rework or interchange the joining module during the tool life while the combined solution provides a higher degree of integration and allows economising one die station. Further, the spatial arrangement of joining and forming process displays a classification criterion. The joint can be located at an area that is not directly affected by the forming operation or at an element of the part that has been formed in a previous die station or in the combined forming and joining station. Furthermore, the synchronization between the joining and the forming operation characterises the process. The joining process can be executed while the ram is in motion or a holding time can be implemented allowing the realisation of slower joining processes. Table 1 gives an overview of the derived variants of integrated joining processes.

Table 1.Variants of integrated joining processes.

	Criterion		
	Position of the joining process inside the die	**Spatial arrangement** of joining and forming process	**Synchronisation** of joining and forming process
Embodiment	Joining module as a separate die station	Joining and forming at different areas of the part	Joining process simultaneously to the forming process
	Joining process integrated in a forming station of the die	Joining at the formed area	Joining process before or after the forming process

In the following, a combined forming and brazing die station is investigated in which the joint is created at the area formed in the same die station. Thus the brazing fit is created in the forming operation. This allows a precise positioning of the parts and the brazing fit. Further, the brazing fit can be adjusted by modifying the parameters of the forming process. In case of an adaptive control strategy this might result in higher process reliability. An additional forming operation takes place in an area of the part that does not directly affect the brazed area. Since all brazing processes require heating and temperature holding times a holding of the ram is necessary to guarantee a high quality of the joint. The chosen variant is displayed by the bold boxes in Table 1.

2.2. Evaluation of brazing process variants

The integration into a forming process chain results in several requirements for the brazing process. The process time is essential, since the brazing operation usually represents the bottleneck. Further, a movement of components of the brazing construction relative to the tool movement should be avoided while the package space should be kept small to ease the integration. A high quality of the joint as well as a large connection area is appropriate, since sheet metal parts usually have to provide a high stiffness. Further, the process's energy consumption as well as environmental and occupational safety represents important criteria for the evaluation of the integrability of brazing processes.

The processes of brazing and soldering are classified in DIN ISO 857-2 (see Figure 1). Soldered parts provide low connection strength [10]. Hence, soldering is not appropriate for most sheet metal parts; e.g. in automotive applications. For brazing by liquids the parts would have to be dipped into a reservoir containing a fluid, e.g. flux, which is hardly feasible inside a press. Flame brazing raises safety and health issues when conducted inside a press [11]. Electric arc brazing and brazing by beam require a movement of the brazing appliance inside the die if an aerial connection is produced. Among the processes of brazing by current, induction brazing and resistance brazing meet the criteria described above [12]. These especially offer low heating times and a high reproducibility. Employing induction brazing a larger connection area can be heated. Hence, in the following the integration of induction brazing is investigated.

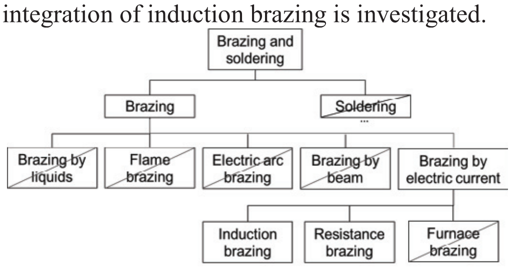

Fig.1. Categorisation of brazing processes [DIN ISO 857-2].

2.3. Focus of investigation

In the following, the feasibility of process integrated induction brazing is verified. A particular challenge results from the realization of the heating process inside the die. Thus influence of the tool on the induction process has to be minimized.

Using the realised demonstration process the integrated process chain is compared to the conventional process chain from a technological and economical point of view. Economically, the realisable cycle time of the integrated process chain is analysed for a reference part. Technologically, the achievable quality of brazed joints produced in an integrated process is subject of investigation. Further, the robustness of the process against varying influence factors, such as the quality of semi-finished products, represents an essential matter for the industrial applicability. Narrow tolerances of the brazing fit are required to guarantee a reliable brazing process. This results in a high accuracy requirement of the forming operation. A particular challenge results from an integrated joining processes at formed area as referred to in Table 1. In this case interdependencies between joining and forming process occur.

3. Conceptual Process Design

3.1. Process development

The process realisation is conducted by producing the tape roller displayed in Figure 2 as demonstrator part. For the investigation of the combined brazing and forming process a single station die is realized. In this station the bending operations for the part's stand and tear bar are performed. Further, a collar as connecting element is drawn and joint to a pipe section building the roll mounting. All these operations are performed in a single stroke. For the production of the part in the die prior blanking of the metal is necessary. The blanks used for the experimental investigation were machined.

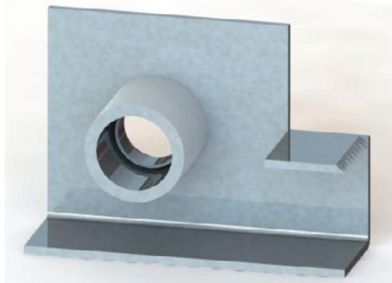

Fig. 2. Target geometry.

A particular challenge results from the combination of the collar drawing process with the joining process using the collar as a connecting element. Since an inductor has to be placed around the joining area inside the die, the application of a blank holder for collar drawing as a tool element is impracticable. Therefore, a process has been developed using a joining component, such as a pipe section or a profile, as blank holder. The developed process works as follows: The inside of a pipe section is coated with flux and equipped with a ring-shaped filler, which is pressed into the pipe. The pipe section is positioned concentric to the hole of a metal sheet. It is rigidly mounted in the direction of the die movement. By employing a loose bearing in the horizontal axis a self-positioning of the pipe concentric to the hole can be realised. By the movement of the die a collar is drawn at which the pipe section provides the function of the blank holder. A triangular brazing fit is created due to the thinning of the sheet metal during collar drawing. In the next step the inductor is powered on liquefying the brazing filler, which flows into the brazing fit due to capillary forces and gravity. The process architecture is displayed in Figure 3. Utilising inert gases the emergence of annealing colours can be reduced or avoided while the cooling process may be accelerated by using a high pressure cooling gas flow.

Employing this process, an additional positioning of the joining elements can be avoided while the accuracy of positioning is very high. The brazing operation can be started immediately after the forming process, a removal of the blank holder is not necessary. By an adaption of the forming process, the design of the joining area can be adjusted. E.g. by using a punch with a larger diameter a partial wall ironing process is realised resulting in an additional non-positive connection.

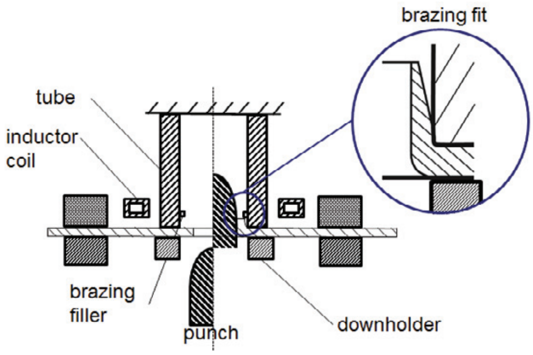

Fig.3. Process architecture.

Due to the plurality of connections of pipes to sheet metal elements several potential fields of application for this process exist. Examples provide flanges for pipeworks tank openings and parts using profiled elements as stiffening such as pedals for vehicles (see Figure 4). Due to the requirement of leak-tightness and high strength of the joint brazing represents an adequate joining technology for such parts.

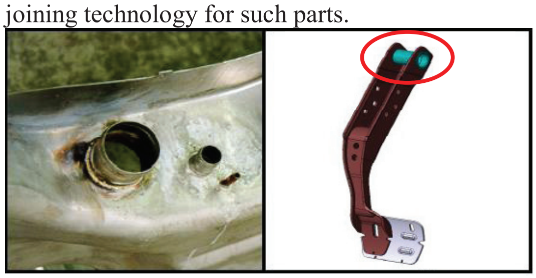

Fig.4.Tank opening (left) and pedal with pipe section as stiffening (right) [source: Brazetec, Brüninghaus & Drissner].

For the realisation of the bending of the part's stand and tear bar a die bending process is applied. The process is less critical since the forming and joining area do not overlap.

3.2. Implementation

A combined forming and induction brazing tool has been realized. The external circuit of the induction unit is mounted inside the press. The inductor coil extends into the die. The induction apparatus further consists of a generator and a cooling appliance from which cooling water flows into the external circuit, the inductor coil and the generator. Both are arranged outside the press and connected to the external circuit by water tubes and electric cables. An inert gas flow through the die is provided to avoid annealing colours and to cool the part down after brazing. Micaceous material inserts are employed in the area around the inductor to avoid a heating of the die. If necessary, silicon nitride ceramic tool components can be used alternatively providing higher compression strength and a longer life time. The collar drawing and brazing process is realised according to Figure 3. The bending process is realised using a blank holder that encloses the inductor coil. An over-bending device is employed to compensate spring back.

4. Experimental Investigations

The possibility offered by servo press technology to almost freely adjust the ram's motion is exploited to allow the integration of the induction brazing process. Fig. 5 displays the ram movement employed for the experimental investigations giving the best results. The total height of stroke is 107 mm, where of 45 mm are working stroke. 256 degree or 71 per cent of the stroke time the ram is held in brazing position. The brazing position is located above the bottom dead centre to ensure an offset between the punch for collar drawing and the inductor coil and thus to avoid a heating of the punch.

The cadmium-free silver brazing solder L-Ag55Sn with a melting point of 650°C was employed for the experimental investigations. This brazing solder allows the creation of joints with a tensile strength of 400 MPa, exceeding the strength of the base materials. These are the deep drawing steel DC04 for the sheet metal and S235JR for the pipe section. The joining zone is prepared with a flux for steel parts based on boron compounds containing fluorides.

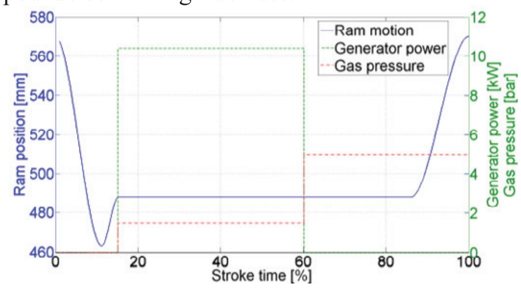

Fig. 5. Ram movement and process synchronization.

Within the investigations a number of 6 strokes per minute could be realised resulting in good parts. For these parts the heating time was 4.5 seconds at a gross electric power of 10.4 kilowatts. Simultaneous to the start of the heating period a low pressure protective gas stream was led into the die. After the heating period a high pressure cooling gas stream was triggered. The process synchronisation is displayed in Fig. 5.

4.1. Assessment of the parts' quality

Fig. 6 shows a part produced using the described parameter set-up. An even height of the collar as well as an exact 90 degree bending angle could be realised. For the experiments conducted employing protective gas small areas with annealing colours are observable, especially inside the pipe. Here the process has to be modified to provide a larger stream of the gas. Compared to a part brazed without inert gas a reduction of annealing colours has been realised.

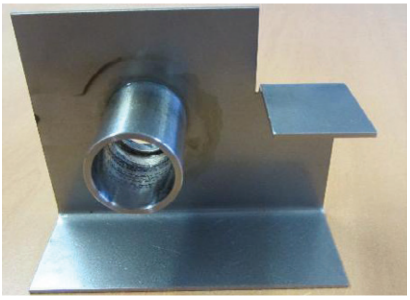

Fig. 6. Part formed and brazed inside the press employing inert gas.

Fig. 7 displays a cross section of a sample part. The brazing solder filled the whole brazing fit. There are no flux residues visible. It can be supposed that a large proportion of the flux is vaporized after the surface has been activated. In some cross sections hollow spaces with a diameter in 1/10 mm range can be observed, especially in tapered area of the brazing fit. Possible reasons for that are to small capillary forces due to the small size of the brazing fit or partial flux residues. Microscopic examination shows that in some cases the brazing solder flows in the approximately 5 µm broad fit between the downside of the pipe and the sheet metal.

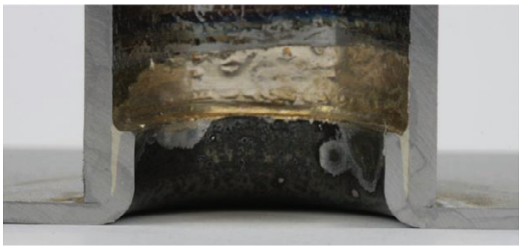

Fig. 7. Cross section of a test part.

Diffusion processes between the molten filler and the base material should occur to guarantee a high quality of the joint. The size of the diffusion zone mainly depends on the used solder and the heating profile [**Error! Bookmark not defined.**].

To investigate the quality of the brazed joints an energy dispersive X-ray (EDX) analysis is conducted. As part of scanning electron microscopy EDX allows the location-dependent identification of the concentration of selected elements. EDX line scans were carried out in the joining zone to analyse the element distribution in the transition zones between brazing filler and the pipe section as well as between the brazing filler and the collar. For the transition zones of both base materials similar results are observed. Fig. 8 displays a characteristic result of an EDX line scan investigating the distribution of iron and silver. While iron is the major element of the joining components, the brazing filler mainly consists of silver. For the investigated samples a zone of 4.5 µm average length containing both elements can be observed which implies the emergence of a diffusion zone. This indicates a good quality of the joint [13]. There is no indication of negative effects on the joint's quality due to the integration in a press such as forces acting on the joint immediately after the standstill of the press in brazing phase. The low percentage of silver indicated in the left part of Fig. 8 is likely to result from measurement noise or from the grinding process necessary for the preparation of the specimen. A limited spectrum of elements was scanned in the EDX analysis. This explains the high fraction of silver in the solder. Therefore, the results should be considered qualitatively but not quantitatively.

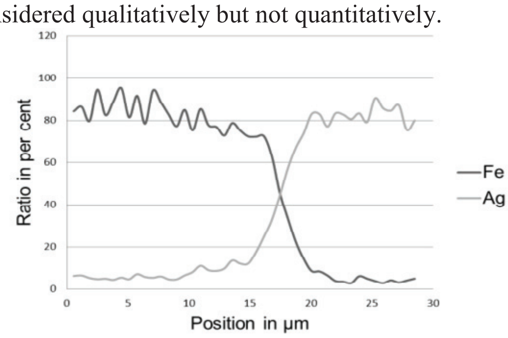

Fig. 8. Characteristic result of an EDX-linescan.

4.2. Assessment of the integrated joining process

Challenges concerning the process time can be coped with by implementing quick heating procedures like induction. Constructive issues accompanied with the integration of an inductive heating process into a press can be solved by employing non-magnetic tool-steel as well as micaceous material or ceramic die inserts. Employing a joining component as moulding element, tool elements are saved and do not interfere with the brazing process and the part handling.

For the demonstrator part a cycle time of 10 seconds could be realised in a first experimental study. Within the development of industrial applications a shortening of the process time especially with regard to the heating strategy is likely to be realisable. By integration the process chain is reduced by the packing, storage and transport and positioning effort necessary for the placement of the formed semi-finished parts inside an external brazing station. Further, the brazing station can be saved. On the other hand an external brazing station can be easily duplicated, which may become crucial since the brazing process usually represents the bottleneck in the process chain. Hence, in case of a high demand this process chain might be economically superior. Therefore, the economic feasibility of an integrated brazing process has to be determined for each application considering the expected demand profile. A particular challenge results from varying demand. Therefore, the spectrum of applicability of both process chains has to be considered against the background of a company's range of products. For the integrated induction process described in this paper the major components of the induction unit can be reused for multiple applications while the tool construction has to be adapted for each part to realise an integrated process.

Since the joining component influences the moulding the collar drawing process described above provides a higher robustness against varying process influencing parameters. The process can be designed in a way that partial wall ironing occurs. For a within delivery tolerances increased sheet thicknesses the wall ironed part of the collar increases. The geometry of the brazing fit is only slightly affected by the changed sheet thickness. Hence, the quality of the joint remains almost constant. Similarly, the influence of varying inner diameters of the pipe on the brazing fit is minimised.

Further, an increased joint strength can be achieved using the described process. The pipe section can be heated up more intensively than the collar, by adjusting the inductor design. Consequently the pipe section is expanded more than the collar when the solder is liquefied. After the cool-down compression stress is superposed to the joint area resulting in an increased joint strength.

5. Conclusion

This paper shows that the integration of brazing in forming process chains is technically feasible. Within the scope of further research the process understanding, especially the interaction between the forming and the brazing operation, are subject of investigation.

An analysis of integrated brazing from an economic point of view is desirable. Therefore, it is necessary to evaluate the different options of integrated brazing processes as summarised in Table 1. A particular challenge results assessment of the economic feasibility, since the integrated and the external process chain differ in fixed and variable costs as well as in their range of application. Here, different utilisation scenarios result in different optimal design choices.

Servo press technology is hitherto mainly used to increase the production output by accelerating the no-load stroke. The investigations described in this paper show an example for the exploitation of the chances offered by servo press technology beyond the aim of increasing press productivity. However, there is still a large unexploited potential for research and industrial application of servo press technology. With regard to process integration the execution of further processes, such as assembling or machining, may be investigated. Additional examples are the reduction of noise emission or the adjustment to changes in the quality of raw materials by an adaptation of the ram motion profile.

Acknowledgements

The investigations presented are part of the research project "Formäleon – Changeable Sheet Metal Forming Utilizing Servo Technology" funded by the German Federal Ministry of Education and Research. The authors express their thanks for enabling this project.

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