Abstract
The electron beam (EB) is in use in industry since about 1950. Besides of thermal electron beam processes like welding, drilling, engraving and surface treatment of metallic materials, non-thermal electron beam processes like the modification of plastic material or the sterilization of seed are investigated at the new electron beam centre at the University of Applied Sciences Dresden (HTW) which is able to perform both kinds of processes. This special EB-process equipment is unique in Europe.

The paper gives a short overview of the “state of the art” in the field and an overview about the latest results in research at HTW. The main part of the presentation deals with the optimisation of a new manufacturing process chain using Electron Beam Technology for manufacturing of individualized medals either as “Hybrid”-medal or full EB-medals and the latest developments in EB-Welding of Titanium-Aluminium for automotive and aircraft applications.

Keywords
Rapid Manufacturing, Electron Beam Application, Individualisation of Products, EB-Welding, Titanium-Aluminium

1 INTRODUCTION
The first application of EB-Technology in industry dates back to the 1950’s. Actually the rapid development in this field is characterized by widespread use in quite different scientific areas. Besides of specialized EB-equipment for serial application in industry the EB-Centre at HTW Dresden is designed for a broad innovative research program both in thermal and non-thermal applications and in this modification it is unique in Europe.

In 2009 this special type of electron beam equipment was installed by the company Steigerwald Strahltechnik GmbH at the HTW EB-Centre. This machine allows the processing of different materials under vacuum for metals and under atmosphere for polymers for different branches of industry.

The research work at HTW EB-Centre was started with an interdisciplinary research team. The Team consist of four young researchers of different faculties. These are the Faculty of Mechanical Engineering, Chemical Engineering, Agriculture / Landscape Management and Electrical Engineering.

2 THE ELECTRON BEAM CENTRE
The EB-Centre is used for teaching and research at the university. The students get some basics knowledge in the electron beam technologies and some experiences in the field of applications. Furthermore it is important to train the young researchers which have different backgrounds to develop their skills and knowledge’s for this technology. In this case there are co-operations with some research institutes such as Fraunhofer Institute of Electron Beam and Plasma Technology (FEP) Dresden, Leibniz Institute of Polymer Research (IPF) Dresden and further local and external partners. The young researcher’s work on different topics around the electron beam facility. The research work includes the welding of mixed metallic compounds, the modification of layer structures for the electronics and coating technology, the irradiation cross-linking of polymer materials such as biopolymer and the electron beam
pickling of seeds. The applied research for industry will bring remarkable results for improving quality of products, solving difficult welding tasks, enabling of new solutions in different fields a.s.o.

3 TECHNOLOGICAL POSSIBILITIES

The highly developed electron beam technique is characterized by an accurate energy input and reproducibility which allows a wide range of applications. The EB-processes are divided into two general types of processes. The material processing under vacuum is called thermal process and the processing under atmosphere is called a non-thermal process [4]. The following figure shows the general electron beam processes and their field of applications.

![Figure 2 - Overview about the field of applications](image)

3.1 Thermal Process

The thermal process is primarily characterized by the use of the thermal energy input in the material. The focused electron beam under vacuum melts or vaporizes the materials.

![Figure 3 - Schematic representation of the thermal process](image)

A great advantage of the beam welding process is the deep weld effect. This means that the kinetic energy of the electrons is used. The electrons created in the EB-generator and accelerated in the vacuum collide with the material and therefore a converting of thermal energy take place. Through the extremely high power density, approximately $10^7$ W/cm² and the small focal spot diameter the material will be vaporized at the target point. The explosively vaporizing process allows the electrons to penetrate deeper in the material. Therefore very thin weld seams can be produced compared to conventional welding processes such as metal active gas welding (MAG).

![Figure 4 - Electron weld seam (left) MAG weld seam (right)](image)

3.2 Non-thermal Process

The non-thermal process is characterized by the modification of the materials through the interaction of the electrons with the molecules of the polymer materials. The processing of the material takes place under atmosphere. Therefore the focused electron beam can spread out about an area of 200 mm x 60 mm to irradiate the material (see figure 5).

![Figure 5 - Schematic representation of the non-thermal process](image)

The electrons are transferred through a Lenard-window from high vacuum to standard pressure (atmosphere). This allows the processing of materials without evacuation of the working chamber after each electron beam process. The main advantages of the electron beam cross-linking are that new material characteristic concerning thermal, electrical, mechanical and chemical properties can be reached. The following figure shows an electron beam cross-linked material with improved thermal characteristics.
4 ENGRAVING OF MEDALS

A special field of application of the electron beam is the engraving of medals. This method is suitable for marking of components, the specific modification of surface structures such as roughness or the plating with other materials. A special task for structuring of metals is the engraving of medals for a variety of occasions such as honorary symposia and commemorative medals [2]. An essential aspect is that each material can be engraved by the electron beam independent on the material characteristics. In the following process chain the manufacturing of medals with the electron beam is demonstrated in detail.

The task was to develop a program which converts the pictures in data for the electron beam facility. The program works according to the following principle. Each pixel of the picture is inspected of its colour. Each separate colour is allocated to a certain hold time of the electron beam on this point (pixel). In addition, each pixel gets a coordinate in X- and Y-direction. These data are stored in a special file and after that transmitted using an interface such as RS232, Ethernet or Proflbus to the electron beam facility. The deposited data result in a deflection figure which can be activated with the numerical control of the electron beam facility. Now the EB processing step comes where the medals are engraved. In this case the electron beam is deflected with a frequency which lies in a range of 4 Hz up to 10 KHz which is depending on the special deflection figure. This principle of the picture generation is already known from the Braun tube. The HTW facility use a deflection unit to control the electron beam in X- and Y-direction. The previously calculated coordinates and hold times are line by line transmitted to the surface of the material. The result is a local fusing of the material. Through the different delay times (hold times) at the actual point (pixel) the contrast of the picture can be controlled. Due to the extremely fast and nearly inertia-free deflection the engraving process needs approximately one second only depending on kind of material and complexity of image. The close collaboration between EB-Centre and the Laboratory for Metal Forming Technology allows the manufacturing of individual medals for different occasions.

4.1 Hybrid Medals

Hybrid medals are characterized by a conventional coining process for one side of the medal (see figure 8). The other side can be individual designed with any picture and layout. Advantages of the high tech equipment are that the electron beam is a wear free tool and independent on the processing material. The following figure shows a hybrid medal variant.

4.2 Electron Beam Medals

A second variant is the engraving of both sides by EB. In this case the front and back side will be processed successively. The engraving time for both sides is only 2 seconds. The figure 9 shows an electron beam medal.
5 JOINING OF VARIOUS TYPES OF MATERIALS

Actual developments in the field of lightweight design for automotive and aircraft applications are characterized by a strategy of using a hybrid combination of different materials such as titanium-aluminium and copper-aluminium [5]. The focus is to produce high quality and economical joints for the relevant area of application. Conventional welding processes come to their limits in this field and it is necessary to use new and innovative welding processes like the electron beam welding. The technology offers the possibility to reach different metallurgical conditions in the weld metal with a minimum of energy input in the materials.

5.1 Joining of Titanium-Aluminium

Conventional welding of titanium and aluminium alloys is very difficult. Actually several research groups investigate the behaviour of both materials under the influence of the electron beam. Aim of the work is to reach a durable connection of titanium and aluminium. There are a lot of aspects which should be considered for the research work. Some of them can be explained at a binary phase diagram (see figure 10).

For an optimum joint it is important to get mixed crystals which are totally and completely soluble. That means that the aluminium material is until 11 atomic percent completely soluble in titanium (green left area on the binary diagram) and titanium material until 3 atomic percent in aluminium (green right area). At 42 weight percent aluminium in titanium the brittle phase area is beginning. At this point it comes to many intermetallic phases which are extremely brittle and influence the mechanical-technological characteristics of the joint negative. Selected alloys such as Ti3Al and TiAl are useable titanium aluminides with suitable toughness and ductility characteristics. Furthermore it can come to void formation and residual welding stresses as a result of disabled shrinkage. Current research work is directed to minimize these disadvantageous effects. First results are shown in the following figures.

The left figure represents a welded joint of titanium and aluminium. The right figures represent enlarged views of the welded joint which was analysed with a scanning electron microscope. Figure a) shows the transition of the heat affected zone of TiAl6V4 to the homogeneous mixed area with a low aluminium concentration. The figure b) shows the transition from the homogenous mixed area to the AlMg3 melting zone. Between these two areas lies the intermetallic phase. All problems like void formation, intermetallic phases and residual welding stresses have to be solved with different strategies in the future. Therefore methods like special heat management, using intermediate layer material, special joint configurations and different electron beam guidance can lead to success.

5.2 Joining of Copper-Aluminium

Copper and copper alloys have higher market prices of about 25% compared to aluminium therefore the industry tries to substitute the copper. A second reason for taking the aluminium is the lower weight which is about 50% less than copper. The vehicle industry (automotive, railway, airplane) want to take aluminium for electrical cables despite lower electrical conductivity of about 33%, increasing of cross sectional area by 60%, reduced tensile strength $R_m$ and danger of electric chemical corrosion compared to copper. Main problem is that almost all electrical connections consist of copper or
copper alloys and it’s therefore important to produce a firmly bonded joint of copper and aluminium. Both materials have different material characteristics which make the joining complicate. The structure of a metallic alloy is generally influenced by three important material characteristics (atomic radius, electro negativity and valence of the element) [1]. These differences have an unfavourable effect of the welding process and the stability of the connection. The focused electron beam positioned directly at the connection point of both metals should enable a positive influence of the molten pool and therefore high strength values in the welding zone, which are not possible by conventional welding methods.

**Figure 12** - EB weld of Cu-Al [4]

But the EB welding seam shows brittle intermetallic phases and even cracks at the surface of the weld (see figure 12). A solution to solve this problem is to minimize the aluminium content in the welding structure by positioning the electron beam towards the copper side but the differences in the melting temperature will not allow a suitable EB welding process. The melting temperature of Al 99.5 is 660 °C and of Cu-DHP at 1.085 °C. Therefore the new strategy selected was the diffusion soldering process. The electron beam is deflected about a specific area over the copper only (see figure 13).

**Figure 13** - Schematic representation of the electron beam diffusion soldering process

The first results of the research using the scan technology shows a nearly perfect diffusion process between the two metals like it can be seen in the micro section (figure 14). The connection seems strong and with sufficient electrical conductivity but it must be investigated in further experiments.

### 6 CONCLUSIONS

The presented investigations show that the electron beam technology is an alternative method for different material processing applications. The newly established research centre at the University of Applied Sciences Dresden has started successful research work both in thermal and non-thermal use of the EB. The presentation could show only some examples. An innovative application of the EB is demonstrated with the engraving of personalized medals for different purposes. The importance of Cu-Al and Ti-Al welding connections for lightweight design in automotive and aircraft industry e.g. will increase in the future considerable and need special research work which was started successfully.

### 7 REFERENCES


### 8 BIOGRAPHY

Jochen Dietrich holds a Dr.-Ing. degree (PhD) in Manufacturing Engineering from Technical University of Dresden in 1978. After several years of research work in industry he continued his research in the field of metal-forming and die-making at TU Dresden. He worked several years as guest professor in Ethiopia, China and USA. He is currently Professor in Manufacturing Engineering at the University of Applied Sciences Dresden (HTWD) (since 1993)
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