Adhesive Workpiece Fixturing for Micromachining

Philipp Blumenthal and Annika Raatz

Technische Universität Braunschweig
Institut für Werkzeugmaschinen und Fertigungstechnik (IWF)
Langer Kamp 19 B, 38106 Braunschweig, Germany
p.blumenthal@tu-bs.de
http://www.iwf.tu-bs.de

Abstract. Even though significant progress has been made in the field of micro production and the development of miniaturized micro production-machines in the last ten years, an explicit consideration of clamping-devices has not taken place. The requirements for clamping technology in the manufacturing of microparts and the manufacturing of macroscale parts are highly different. Special clamping devices for each sector are needed. This article presents the designing of a special adhesive micro-clamping device for micro production. The clamping force is applied by fixing the workpiece to the clamping module using hot melt adhesives. Thus high surface pressure and damage to the micro-component is avoided. The development of this adhesive clamping device is a first implementation of a novel and promising approach for micro production. Basic functioning could be confirmed by practical tests.

Keywords: Adhesive, Clamping, Fixturing, Hot Melts, Micromachinig.

1 Introduction

For over a decade, the demand for small components with dimensions of less than one to a few millimeters has been continuously increasing, especially through the growing fields of biotechnology and medical technology [7]. Due to the miniaturization of existing products, the development of novel micro-components and the increasing demand for functional integration, both the applications of micro-components and the components themselves have become more diverse. This leads to an increasing complexity of the structures of micro-components and the use of different materials. At the same time ecological and economical pressure in the production increases. For this reason, a constant improvement of existing manufacturing methods and the development of new methods and concepts for micro-manufacturing is needed. Since conventional production techniques such as LIGA are limited in their area of application and range of producible structures, the high-precision production of a variety of complex three-dimensional micro-components out of different materials is not possible without the use of chipping technologies. Since these facts have long been known micromachining is already state of the art, as can be seen in the increasing demand for micro tools [10]. However, one important aspect which has not

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been sufficiently studied are the devices to hold these pieces in place. This aspect is of particular interest as these small parts offer little clamping surface and are susceptible to damage. In micromachining, new methods and design options for clamping devices arise, which would not be feasible for macroscopic parts [11]. Therefore, an intensive examination of the clamping technology for the use in micro-processing machines is essential. In the next section, requirements for clamping systems for micromachining are presented. Different clamping technologies are regarded and their suitability for micromachining is analyzed. In the subsequent section, a novell fixturing concept on the basis of hot melts is demonstrated. The design principles are explained and first experimental ruselts are presented. Finally, a summary and an outlook is given.

2 Clamping Technology for Micro Production

For each machining task both the tool and the workpiece need to be reliably fixed in a defined position. Every clamping device, regardless of its specific shape, has a significant influence on the work quality, efficiency and reliability of a machine and therefore a decisive influence on the success of the resulting product. For this reason, clamping devices are adapted individually to a workpiece, machining task and the machine, which leads to an enormous amount of specific clamping devices [9]. A well-desgned clamping device must ensure that there is no pressure on the workpiece that would result in material stress, no restriction of access for tools and a uniform application of force across the entire part.

Clamping systems for micromachining basically have to fulfill the same requirements as clamping systems for macroscopic processing. These requirements are mainly [3] [8]:

- Fast and flexible clamping to improve productivity
- Careful component clamping of fragile workpieces or delicate surfaces
- Clamping of geometrically complex parts
- High reproducibility and accuracy to improve quality

This is probably why in micromachining mostly established clamping devices from traditional machine tools are used, whereas specific clamping devices are rarely found. In some cases these conventional methods are well suited, while in others the resulting performance is suboptimal. Particularly, it is not easy to simply scale down traditional methods for micro-fabrication. Especially, the commonly used force-fitting clamping in traditional macro-manufacturing reaches its limits on micro-components. The widely used mechanical, vacuum and magnetic clamping do not meet the requirements to clamp small and complex parts satisfactorily [11]: While magnetic clamping technology is constrained by material limitations, vacuum clamping is limited due to the small effective areas and insufficient holding forces. In the mechanical fixturing however, high tension peaks can arise from the small contact areas, which quickly lead to damage to the components. Still these methods are frequently used in micro production. This is acceptable if the micro-components are machined from a larger body, which can be clamped securely with known clamping means and when clamping marks are uncritical. However, this contradicts an economic production and restricts the machinable geometry and the further processing of partly finished goods. In addition to these traditional techniques there are other methods, some of which have more potential in terms of fixturing small complex parts. These clamping methods are described in the following.

The concept of freeze-clamping, which is used among other things for clamping limp or complex workpieces in the macro production, is also applicable for clamping small and micro parts [11]. It is a combination of force-fit and form-fit clamping. Water, which is in a gap between workpiece and clamping device, is cooled down to -10°C. This freezing process causes the workpiece to adhere to the device. This can be accomplished for small parts with Peltier elements, for example. The clamping force can be increased significantly by surrounding ice or additional clamping aides, such as rests. With a freeze-clamping device developed at the Institute of Production Engineering (LaFT) of the University of the German Federal Armed Forces, a clamping of parts with dimensions of 2 x 2 $mm^2$for milling was tested successfully [11]. Also, the use of wax and surfactants as an alternate tensioning medium was considered at LaFT. The freeze-clamping encounters its limits if during processing a high heat intake takes place, coolant is to be used or a continuous power supply is not available to the clamping system, since a constant cooling is necessary. For cooling, an external heat exchanger and associated coolant tubes are required, whose placement can be problematic.

As part of the European Project MAFFIX [3] another clamping method was developed. Magnetorheological fluids are used, which solidify in a split second if a magnetic field is activated. By this effect, work pieces which are embedded in the liquid can be fixed. When switching off the magnetic field, the material falls back into a liquid state so that the fixation is released. The advantage of this technique lies especially in the clamping of uneven workpieces of medium and large sizes without high tension forces acting on the workpiece. By embedding the pieces in the magnetorheological fluid, differently shaped and curved structures can be clamped quickly. For limp or flat workpieces, the magnetorheological clamping cannot be used because it represents a form-fit clamping procedure.

Furthermore, it is possible to mold work pieces in low-melting metals (e.g. bismuth alloys) as done in the ”Reference Free Part Encapsulating” (RFPE) [6]. In this clamping process the parts are fully encapsulated in a defined form. The material of the form and the casting-material are identical. In a machine tool, the form (and with it the workpiece) can be precisely positioned due to known reference marks of the form. The advantage of this method is therefore the simple and reliable tensioning of the encapsulated workpiece and the extremely low positioning errors. Through the support effect, a complex 3D machining of delicate, fragile structures is possible. A disadvantage of RFPE along with the high cost of the mold, removing of the casting-material as well as the reduced accessibility, is the additional casting process which must take place in between the processing steps. Furthermore, the necessary machining of the casting medium leads to an increased tool wear and longer process times. It is also difficult to clamp already-machined parts for secondary operations exactly, since only the repeatability of clamping a moulded part is high.

The clamping of workpieces can also be achieved using adhesives. Here, two types are distinguished: First, the fixation with liquid adhesives and second the fixation with adhesive films. For distortion-free fixturing of thin-walled, flat pieces of limp material, double-sided adhesive films are commercially available. The clamping of non-planar components with liquid adhesives has not been extensively researched. Using liquid adhesives, the clamping quality is affected by the adhesive and cohesive strength and the wetting, which depend on the adhesive and the material of the workpiece and the clamping device. Since liquid adhesives are not easily controlled and the curing is time-consuming, they were only used in macro manufacturing when no other clamping methods where applicable [2]. Due to the positive characteristics of the adhesive fixturing, continuous improvements and developments were made on this field, mainly regarding defined bonding and debonding. Since 2004, the Dept. of Industrial & Manufacturing Engineering, Pennsylvania State University [1] developed an UV-light activated adhesive gripper for achieving short bonding times. The possibility of temporarily fixing workpieces for machining by means of adhesives has also been highlighted by the Fraunhofer Institute for Manufacturing Engineering and Materials Research (IFAM) [5]. They identify adhesive clamping as one possible application of newly developed specifically debondable adhesives.

For micromachining, experimental studies on adhesive fixturing were carried out at the LaFT for example, where small structures of about 1x1 mm^2 were successfully cut out of workpieces which were bonded by adhesives to a substrate. However, a disadvantage was the difficult separation of the connection and the removal of adhesive residue from the workpiece. The use of solvents and the heating of the components was necessary, which is both costly and also contradicts an ecological production.

3 Concept of Adhesive Fixturing with Hot Melts

The Institute for Machine Tools and Production Technology (IWF), TU Braunschweig investigated the possibility of fixturing components with adhesives. A new concept of adhesive fixturing with hot melts was developed having a high potential in clamping of flat, complex-formed, workpieces of different materials. The adhesive fixturing was regarded, since it usually has the same advantages as vacuum or magnetic clamping: free machining on five sides, distortion-free clamping of thin, fragile or limp workpieces. However, it requires no continuous external supply of energy, allows for small workpieces significantly higher retention forces and has a significantly higher geometric and material flexibility.

The adhesive clamping device is not limited to machining tasks, but can also be used for assembly tasks. After machining, the part can remain clamped for subsequent assembly processes. Due to the known position of the part relative to the device, an accurate positioning can be achieved by clamping the device. Position information can be passed directly from the machining process to the assembly process. This not only saves time, but has one fixation system for the entire process. Since the requirements for clamping are normally higher in machinnig tasks than in assembly, the focus is set on machining.

3.1 Design

In adhesive clamping, the fixturing of workpieces is generally less problematic than the relaxing, because a defined debonding of adhesives is often hard to achieve. Therefore hot melts (HM) were analyzed for the use in clamping devices. HMs are thermoplastics which allow an easy debonding through heat without the use of solvents.

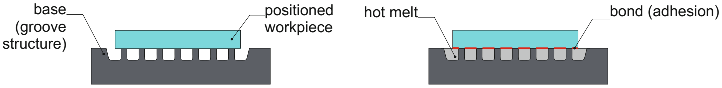

Fig. 1. Fixturing-principle using hot melts

In the concept developed at the IWF, the workpiece is first positioned on a base (mounting area) and then bonded to it by inflowing HM (Fig. 1). Strategies for the application and removing of the HM were analyzed as well as design principles for the mounting area. Simulations made with Ansys CFX show that a groove-structure with contains small channels on which the workpiece is positioned is suitable. The HM is fed through an inlet in these channels and flows to the positioned workpiece. Here the HM wets the part from underneath, while the top and sides remain free from HM and are accessible for machining. The geometry of the groove-structure depends on the HM, especially the viscosity. Simulation allowed the determination of a maximum permissible viscosity for a steady flow of HM in channels narrow enough for clamping small pieces. A tested channel width of 1.5mm in the mentioned groove concept resulted in permissible viscosities below 1000 mPa.s (Fig. 2). Utilizing this groove-structure and a very low-viscosity HM leads to the following principle of the clamping process, see Fig. 3. The component to be machined is positioned on the base. Then the base is heated so that liquid HM can flow into the channels and wet the component. After cooling, the machining process can begin - the component is fixed by the adhesive securely. By defined heating of the structure after the processing, theHM liquefies, the connection is released and the workpiece can be removed. Depending on whether any further work should be carried out on the system, the liquid HM is removed from the station or left there for fixing the next component. This reversible adhesion and the easy loosening is a decisive advantage of HM over other adhesives in clamping technology.

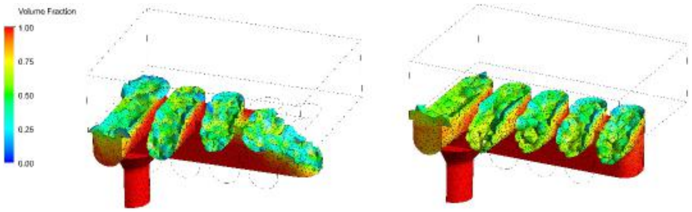

Fig. 2. Volume fraction of HM during flow simulation in groove-structure. Viscosity on left figuere (2000 mPa·s) is too high, viscosity on right figure (700 mPa·s) appropriate for selected structure.

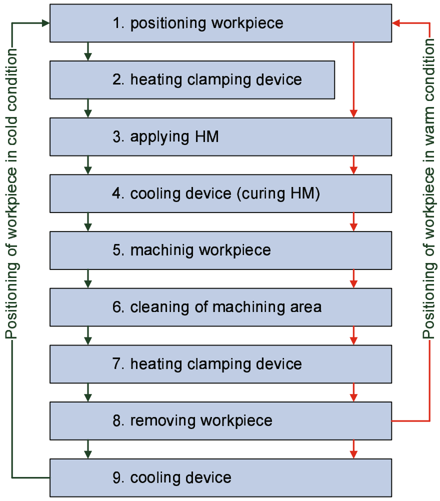

Fig. 3. Process cycle of adhesive fixturing with hot melts

3.2 Testing

The design concept was implemented for a function test. As tension medium HM with an extremely low melting viscosity of 300 mPa·S was used. The results of the experiments show that small workpieces of different materials and various workpiece geometries can easily be clamped (Fig 4). The basic functionality of a hot melt clamping method could be demonstrated. Initial shear tests revealed an average bonding strength of about 1.7 N/mm^2. This value can serve as an estimate of the order of magnitude and represents a minimum strength which can easily be achieved. This bonding strength is not yet sufficient for industrial use, where working forces of about 10 N arise [4].

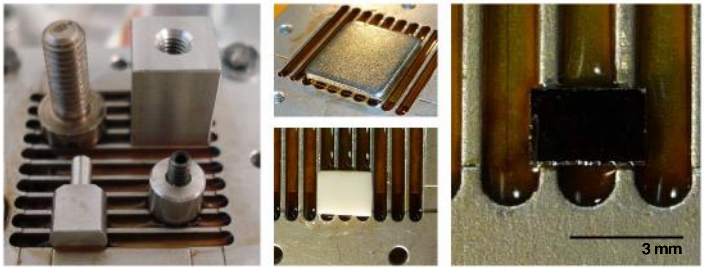

Fig. 4. Microparts clamped with evaluation model of an adhesive fixturing device

The process time for clamping a component depends on the characteristics of an individual HM clamping device. In general, for the heating, applying and cooling of the HM considerably more time is required than for conventional clamping with mechanical clamping means. In this particular adhesive clamping system a time for clamping and releasing operation of several minutes is required, due to slow cooling behavior. Therefore, the optimization of the clamping duration must be the subject of further investigations. Final examinations, such as the strength of the bond in dependence on the material, as well as the development and analysis of other basic concepts are planned for future research. Thereby it is expected to achieve a design for reproducible fixation with high clamping strength as well as high flexibility.

4 Summary and Outlook

This article describes that particular requirements for clamping systems for micromachining arise, and therefore special clamping devices are required. Of particular importance in micro production is the avoidance of component damage due to high surface pressures, the unhindered access for a five-sided machining, and the suitability for a wide range of materials. These requirements led to the development of an HM-based adhesive fixturing method. Following the analysis of HMs and the simulation of their flow behavior, a first concept was designed and an evaluation model built.

In initial experiments the basic functionality of the adhesive fixturing method was confirmed. Already the functional model distinguishes itself by the following positive characteristics:

- Fast and flexible clamping to improve productivity
- Uniform force distribution over the whole workpiece
- Unrestricted free access for 5-sided machining
- Clamping of different materials (metals, ceramics, silicon, glass)
- Use of other HMs possible if required

However, at the current state this first evaluation model needs further improvement. One reason is the required time for clamping and releasing operations, another the insufficient bonding strength. Additionally, investigations involving the examination of adhesives are planned, since the use of HMs with higher bonding strength, better wetting behavior and lower processing temperature is desirable. Disbond on Command adhesives are considered in this context. These are adhesives that are selectively activated and deactivated. For this purpose, nanoparticles are added to the adhesive, which are stimulated by microwaves or magnetic fields to vibrate. Thereby, heat is released and delivered to the adhesive, activating the latter.

Carrier systems in micro production systems are a very promising area of application for adhesive fixturings. Here, the clamping is not done inside the machine tool system and thus a prime-time concurrent clamping is possible. The developed adhesive clamping method can complement and expand the existing clamping technology very well and contribute to a more economical manufacturing of small- and micro-components. It is expected to increase the potential of adhesive fixturing significantly through the use of innovative adhesive systems.

Overall, the successful implementation of the adhesive clamping model demonstrates the far unused potential of innovative fixturing concepts. Further research of the use of adhesive fixturing for micromachining can be addressed on the basis of the developed concept.

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