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# Design Guidelines for Additive Manufactured Snap-Fit Joints

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**Abstract**

Snap-fit joints are one of the cheapest and fastest connectors available. However, due to geometrical complexity of the joints and the limitations of injection molding, they are used almost exclusively in large-scale manufactured products. Additive manufacturing offers the possibility to create end-user products in small and medium numbers with almost unlimited design complexity. This clears the way for new solutions using snap-fit joints to be explored. In this contribution, the existing design guidelines for snap-fit joints are challenged with the design potentials of additive manufacturing. The general working principles of snap-fit joints prove to be simple, clear, and safe independent of the manufacturing process. While the principles remain unchanged, the advantages of additive manufacturing are utilized to improve the integration in the product and the user handling. By applying the design restrictions of the additive manufacturing processes Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) the existing guidelines are extended for new manufacturing processes. To demonstrate the new concepts and the capabilities of additive manufactured snap-fit joints a showcase is conceptualized, designed in detail and produced using Fused Deposition Modeling and Selective Laser Sintering. A lid of a container, similar to a jar, is designed as an integrated single component. Aspects of haptics and usability are integrated, resulting in a lid that can easily be assembled and disassembled using one hand only. The design features springs and snap-fit joints adapted to the advantages and limitations of additive manufacturing.



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*Keywords:* Additive Manufacturing; Selective Laser Sintering; Fused Deposition Modeling; Design Guideline; Snap-Fit Joints

## 1. Snap-Fit Joint

Snap-fit joints are an efficient and easy way to assemble parts without the need for tools or fasteners. The two parts are pushed together and snap-fits lock their position. The user doesn't necessarily have to have access to the snap-fit joint in order to assemble it. Because of this simple procedure, snap-fit assembly can be automatized easily [1]. Depending on the design of the snap-fit the connection is either permanent or can be released by a force or tools.

The key criterion of snap-fits is the displacement of flexible features during assembly and disassembly. Snap-fit joints are often used in plastic parts. The elasticity and permitted strain of plastic materials allow large deflections without damage to the part. Other, less flexible materials require additional elements like metal springs [2–4]. In the joined state the snap-fits are usually load free or have only small displacement. This is especially important for plastic snap-fits, because stressed plastics tend to creep and will lose any pretension over time [3,5–7].

Due to the flexibility of snap-fits additional, stiff locator elements are needed to align the joining partners. Without this alignment a force on the partners can displace the snap-fit and release the form fit of the joint. Lugs, catches or recesses are common features to prevent this. [2,8]

Snap-fit joints are used in a large variety of applications. A few basic types of connectors can be freely adapted and combined to meet the requirements and circumstances of a given design situation. This results in a large diversity of design examples. The three most common types are presented in the following subsections.

### 1.1. Cantilever Snap-Fit Joints

Cantilever snap-fit joints are the most common form of snap-fit joints. They are easy to implement in a design because they have a simple geometric shape and the strain during joining is easy to calculate. The basic design is depicted in figure 1 and consists of a cantilever beam with a tapered hook at its tip and a matching recess in the joining partner. The tapered surface slides along the surface of the joining partner and bends the cantilever. In the final position the hook reaches the recess and snaps back into the undeformed state. Depending on the surface angles of the hook and the recess the joint is either permanent or releases at a separation force against the engagement direction.

The cantilever doesn't necessarily have to be a straight bar. Other designs with L- or U-shaped cantilevers are also common in plastic parts. Those shapes have two main advantages: (i) the cantilever is longer compared to a straight bar without using more space, thus allowing lower deflection forces in compact


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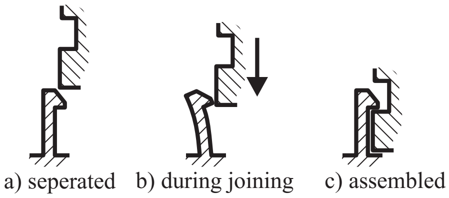


Fig. 1. Displacement of cantilever during joining

situations, and (ii) L- and U-shaped cantilevers on the edge of a part don't require sliders in an injection molding tool.

*1.2. Torsion Snap-Fit Joints*

While cantilever beams are deflected by bending of a beam the torsion snap-fit primarily deflects by twisting of a bar. Figure 2 depicts examples of torsion snap-fits. Torsion snap-fits like the one depicted in figure 2(b) are a simple method to create separable connections. Extending the beam of the hook beyond the axis of the torsion bar creates a seesaw mechanism. A push on the free end of the beam lifts the hook and releases the joint.

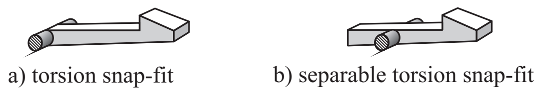


Fig. 2. Permanent (a) and separable (b) torsion snap-fits

*1.3. Annular Snap-Fit Joints*

Annular snap-fit joints are often used to connect circular or elliptic parts, like containers/lids or pens/caps. In this type of snap-fit joint a ridge around the circumference of one part locks into a groove in the second part. During the assembly tensile or compressive hoop stresses occur together with bending. These multiaxial stresses can be a challenge in designing the joint properly [2,5]. For simple circular geometries with constant wall thickness the strain can be estimated based on the different diameters of the joining partners [9].

The key property of annular snap-fits is the stretching and compression of the circumference. A circular arrangement of hooks is not an annular snap-fit, because the deflection is bending dominated [2].

Figure 3 depicts two examples of annular snap-fit joints between a cylindrical jar and its lid. The difference between both designs is that in figure 3 (a) the jar is stretched while the lid is compressed and in figure 3 (b) the deformation is vice-versa. [2]

Depending on the design of the joining partners annular snap-fit joints exhibit very different properties. They are easy to lock and release like in pen caps or provide a permanent, non-releasing, connection depending on the angles and diameters of the joining elements. In both cases a free rotation may be permitted [2].

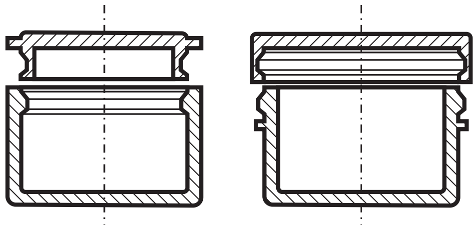

Fig. 3. Examples of jars with annular snap-fit joints [5]

*1.4. Conventional Manufacturing of Snap-Fit Joints and Design Restrictions*

As mentioned before most snap-fit joints are found in plastic parts, because of the elasticity of this material. Snap-fits are also found in parts made from other materials like wood [10] or metal [4] but are less common. Therefore this section will focus on manufacturing and design restrictions of thermoplastic snap-fit joints.

The majority of thermoplastics are processed by extrusion, which is a continuous process to manufacture simple, elongated shapes like tubes, sheets and films [11]. The design of snap-fit joints is limited in this process to simple cantilevers. An example for extruded snap-fit joints is found in cable ducts. Second in terms of processed mass comes plastic injection molding [11]. Injection molding is capable to mass produce complex parts at high quality and low costs [12,13]. The process allows the integration of different mechanical functions like guides, snap-fit joints and other features into a single part.

A key element in the injection molding process is the tooling. Molten plastic is injected into the mold, cooled down until it solidifies and the finished part is ejected. The tooling is a sophisticated, high-tech product with many mechanical and thermal functions that determine the productivity of process and the quality of the produced parts [12–14]. This makes the tooling a significant upfront investment. The complexity and cost of a tool can be reduced by proper design the plastic part. One cost driver in injection molding tools are sliders. Sliders are needed to form and demold undercuts on a plastic part. Undercuts and the need for sliders should be avoided by designing plastic parts accordingly. Figure 4 shows three different designs of a cantilever snap-fit. The undercut in figure 4 (a) requires special provision in the injection molding tool for demolding the part. If the hook is designed with an angle so that the snap-fit joint can be disassembled by a separation force and the cantilever can deflect in the open mold, then it is possible to demold the part by force. More common and applicable to all types of undercuts are sliders, which are pulled back during demolding. In some cases it is possible to integrate the snap-fit into the design of the ejector pins of the injection molding tool [14]. In general it is better choice to avoid undercuts during the design of a plastic part and reducing the effort to design and manufacture the tooling. The examples in figure 4 (b) and (c) do not need any special provisions for demolding, because the hooks of the snap-fits are accessible from the other half of injection molding tool. In figure 4(b) a slot in the part allows a slender element to reach across the cavity and form the hook. The tooling for the design in 4(c) is even simpler, because the designer can place the separation line of the tool along the edge of snap-fit.

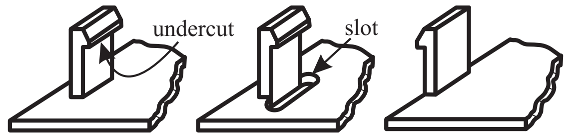


Fig. 4. Design measures to avoid undercuts at injection molded snap-fit joints [6]

Similar design principle can also be applied to other types of snap-fit joints.

## 2. Additive Manufacturing

The term additive manufacturing refers to a group of manufacturing processes capable of manufacturing three-dimensional objects by adding material in a layer-by-layer process based on a 3D-CAD-model and without any tooling [15]. The additive manufacturing processes cover a wide range of process mechanisms and materials. The mechanical properties and long term stability of the produced parts depend on the applied process. Some processes for polymers, like stereolithography and binder jetting, are primarily used for prototyping while others, like fused deposition modeling (FDM) and selective laser sintering (SLS) provide sufficient stability and robustness for end-user parts. [16–18]

In the process of fused deposition modeling a thermoplastic wire is extruded through a heated nozzle that is moving over a building platform. After one layer of plastic strains is deposited according to the geometry of the part the building platform is lowered by the thickness of a layer and the next slice of the part is deposited. The mechanical properties of FDM-parts exhibit a distinct anisotropy. The material is significantly stronger along the plastic strains and show inferior properties perpendicular to the strains. This is due to the poor connections between the molten plastic and the already placed strains. Improving this connection and thus reducing the anisotropy is a topic of ongoing research. [19–21]

Selected laser sintering is an AM process where a laser beam scans a powder bed and selectively solidifies a thermoplastic powder. Once a layer is processed the powder bed is lowered by a layer thickness and a coater applies another layer of powder to the bed. The laser beam melts the powder and part of the surrounding solid part and ensures a good connection between the melt tracks and across layers. In this welding process only a minor anisotropy is observed. [22,23]

Plastics additive manufacturing technologies have a strong economic advantage over conventional manufacturing processes like injection molding, because additive manufacturing doesn't require any tooling and produces parts directly from a CAD-file. Therefor no upfront investment in expensive tooling is needed which allows small lot sizes and even highly individualized plastic products at reasonable costs. [24]

Another advantage of additive manufacturing common to all processes is the freedom of design. The layer-by-layer process allows new designs previously impossible to manufacture be conventional processes and thus improving the functionality of part end product [25]. For a designer this is challenge and opportunity at the same time, because he is required to leave the ground of familiar and proven designs to come up with innovative new solutions. The first step in this process is to identify parts and assemblies where additive manufacturing offers a benefit [26]. After deciding for a suitable design strategy [24] he develops a design concept and proceeds to detailed part design.

Today there is little (but growing) support for the last two steps of concept development and detailed design. A few design guidelines were published in the last years that provide information on the design limits for certain elements e.g. minimum wall thickness in different processes [27–29]. This kind of information is of high value during detailed design. In the concept phase it is of little use, because the guidelines don't show ways to implement certain function. For guidance on this feature level a designer has to find inspiration from examples of good AM designs. The following guidelines and example are intended to show new possibilities for snap-fit joints and how to overcome restrictions of additive manufacturing by design.

## 3. New Designs for Additive Manufactured Snap-Fit Joints

Based on the previously described properties of snap-fit joints the user interacts during two operations with a snap-fit joint. He closes the connection by pushing the two parts of a joint together. If the joint is designed to be separable he also operates the release mechanism to open the joint. In between those interactions the joint has to remain securely closed.

### *3.1. Connection*

Within the current design restrictions of injection molding good designs of the mating process of snap-fit joints are known and feasible. Locators help the user to align the parts and guide the movement until a snapping sound indicates that the connection is made. Process and design fulfill the criterion of being simple, clear and safe [30]. The authors therefore see little room for major improvements to the connection of snap-fit joints although the freedom of design allows an improved handling by a better placement snap-fits and locators and a longer lifetime due to less stress peaks. Nevertheless the general design needs to be adapted to the restrictions of the different manufacturing process. Instead of keeping the tooling simple and avoiding material accumulations the designer has to incorporate the characteristics of additive manufacturing like anisotropic mechanical properties into the design.

The topic of anisotropy has been addressed in the past from a process point of view. Various authors pointed out that it would be beneficial to incorporate geometry and load cases into the filling strategy of AM processes with anisotropic material properties. Figure 5 depicts two different toolpaths in a cantilever snap-fit produced by FDM. The cantilever is oriented in the $x,y$-plane of filament placement. The example in figure 5(a) exhibits a poor orientation with principal stresses perpendicular to the filaments. The orientation in figure 5(b) is more favorable because the strong direction of anisotropic is aligned along the direction of principal stresses [19].

This proposed solution of load adapted filament placement is of limited use to engineers. First of all a load adapted strategy is not implemented in commercial software yet. The machine

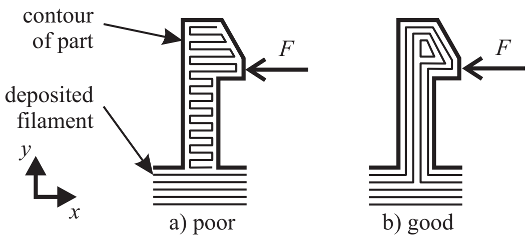


Fig. 5. Poor (a) and good (b) toolpaths to place filaments in a snap-fit according to [19]

operator has a limited set of general options for the path planning and can't choose individual strategies for different sections [31]. Second it is applicable to only a few types and orientations of snap-fit joints. No filament placement strategy will solve the problem of poor mechanical properties if the cantilever beam is oriented in build direction.

Figure 6(a) depicts a classic cantilever snap-fit design with the beam oriented along the build direction *z*. The design is poor, because the bending stresses are in the weakest direction of the material and the staircase effect causes notches with stress concentrations. The freedom of design in additive manufacturing gives designers the opportunity to choose the direction of deflection independently of the given joining direction. In figure 6(b) the beam is perpendicular to the joining direction. During snap-fit joining the material is stressed along the stronger directions of the anisotropic material and the notches between layers have less impact on the durability of the cantilever beam. An additional feature of the beam in figure 6(b) is its curvature to fit into the overall design of the demonstrator described in section 5.

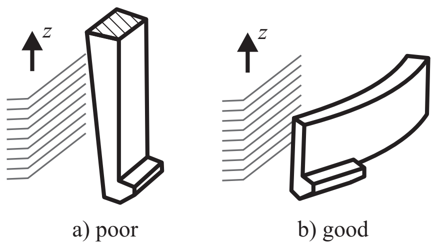


Fig. 6. Orientation of cantilever beam with respect to build orientation

The separation of joining direction and the orientation of the flexible features of snap-fits is the biggest extension to existing design rules when it comes to the joining process. Some snap-fit joints are required to be separable either by force or by a release mechanism. The following section shows design opportunities of additive manufacturing for releasing snap-fit joints.

### *3.2. Release*

There are different ways to release a snap-fit joint. In general the snap-fit joint releases either by a separation force against the joining direction or by other means to deflect the snap-fit. The first method calls for a design where the hook exhibits a slope similar to the one in joining direction depicted in figure 1. By pulling on the snap-fit joint the hook slides along the sloped surface and is deflected until it becomes free of the recess in the joining partner. Additive manufactured separable snap-fit joints behave similar to conventional ones and the same dimensioning rules are applicable [32].

A different mechanism is needed for snap-fit joints that must not separate under a separation force, but should be separable by other means. The torsion snap-fit in figure 2(b) is such a simple mechanism.

Additive manufacturing's ability to produce multiple, already assembled parts in one build job allows creating more sophisticated kinematics to release the snap-fit joint. The user interaction is no longer directly translated into a movement of the snap-fit, but can be altered to perform complex operations of multiple components. The integration of control guides and cams to convert a simple translational user input into different stages of a release process does not necessarily lead to higher manufacturing costs since the production costs of additive manufacturing are primarily driven by volume and not by complexity.

## 4. Design Guidelines for AM Snap-Fit Joints

Additive Manufacturing offers a higher freedom of design compared to conventional manufacturing technologies. Nevertheless the designer has to follow a few design rules. Those are summarized here:

General design rules of the chosen material and AM technology e.g. feasible wall thickness and gap width [27,29].

The designer has to pay attention to the movement of different components in his assembly. Especially the staircase effect on sloped surfaces has a strong impact on the smoothness of the relative movement between parts. A movement along the steps is smooth while a movement perpendicular to the stairs gives a ratchet or chattering sound and feel.

When using an AM process with a pronounced mechanical anisotropy the designer has to consider the load cases as well. The durability of the part increases when it is oriented in the building chamber according to the principal stresses. A possible conflict between smooth kinematics and stress oriented toolpaths can be resolved by changing the design as shown in figure 6. Therefore the orientation of the assembly during the build process should be determined early in the design process based on the desired motion of the parts and the load cases.

Additional design features can make the post-processing of a part easier. When using powder bed based AM processes additional openings in the structure help to remove powder out of channels, guides etc.. If the chosen AM process requires support for overhanging structures those should be accessible to mechanically remove them after the build process. Some processes and machine manufacturers allow the use of a second material to build the support structure from soluble material [16]. The design should allow a sufficient convection of the solvent around the support by adding additional openings.

These design guidelines are not restricted to snap-fit joints, but can be applied for different AM processes and applications. In addition to following the guidelines a designer should also study different design examples and transfer the presented concepts to his specific application. The following section presents a snap-fit and release mechanism as an inspiration.

## 5. Concept Demonstrator

A showcase was designed to demonstrate the strengths and possibilities of additive manufactured snap-fit joints. In addition to the lock and release function, the showcase was designed as a single part without any assembly necessary. To demonstrate a variety of new kinematics and handling concepts the lock and release features are separated in the design. In order to be easily accessible and interesting to people, the showcase is haptically attractive and invites people to play with it. This includes moving parts and a similarity to everyday objects or actions.

The showcase is the lid of a jar as it is found in many households, workshops and offices. For a conventional threaded lid two hands are necessary to assemble and disassemble it. The showcase replaces the lid this with a design that can be closed and opened single-handedly. Assembly is accomplished through a translational movement and disassembly through the rotation of a control ring on the lid. Both actions are possible without highly coordinated movements allowing for an easy handling even without visual contact.

The lid was prototyped on an FDM-machine and the final design was manufactured by selective laser sintering. This was necessary because of the poor mechanical performance of FDM which lead to the delamination of filaments in areas with large deflections. During the change from one additive manufacturing process to the other a few modifications were made, especially the gap width had to be increased to improve the removal of powder. In both additive manufacturing processes the bottom of the lid is facing upwards to reduce support material in the FDM process and to avoid any stairs on the sliding surfaces of the control ring.

Figure 7 depicts the bottom view of the lid. Some important features are highlighted by different colors. The assembly mechanism is a modified cantilever design. As described in section 3.1 the cantilever beams, marked in green, are perpendicular to the build direction so the bending strain occurs within the layers. Locators are placed around the circumference take lateral forces on the lid. Without those locators one can open the lid by a push on the side. The bottom view also reveals small openings to remove residue powder from the gap between lid and control ring.

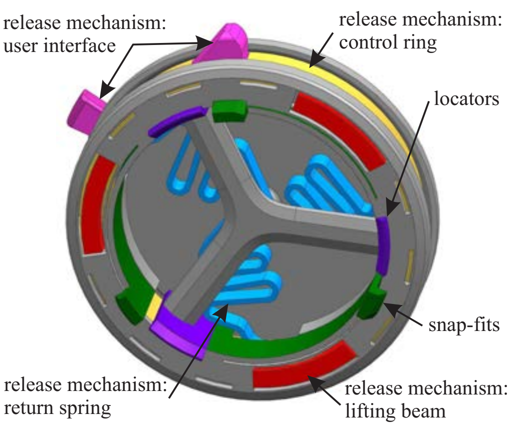


Fig. 7. Lid with snap-fit and release mechanism

The release mechanism consists of multiple elements that are connected to one single part. To activate the mechanism the user pinches the two elements of the interface together. This rotates the control ring and retracts the snap-fits from the locking position. Figure 8 depicts a section of the lid showing the control indentions in ring and the corresponding cams on the snap-fits.

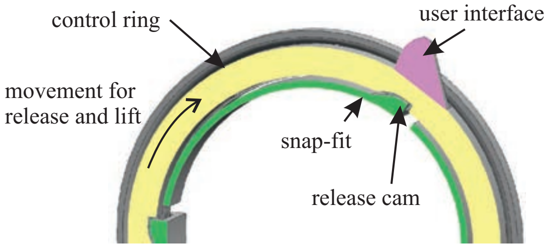


Fig. 8. Release mechanism to push the snap-fits back

A second action is integrated in the release mechanism to promote the separation of the lid from the jar. Figure 9 depicts a second set of control surfaces which is placed on the top of the ring. After the snap-fits are retracted the control ring is rotated further and this second set is acted. The control indentions in the ring slide on the cams of the lifting beams, marked in red in figure 7. The beams bend, push against the rim of the jar and lift the lid above the locking position.

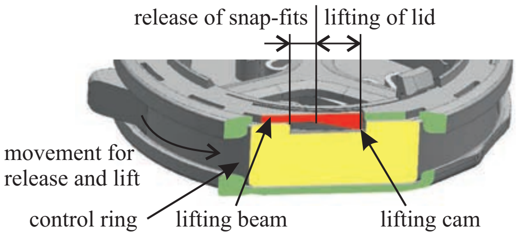


Fig. 9. Release mechanism to lift the lid of the jar

In the final position of the control ring hits an end stop blocking any further rotation. The control ring is returned into the initial position by integrated springs. In figure 7 the return springs are highlighted in blue. The spring's ends merge into the control ring and the center of the lid. The lid is therefore a single highly complex part with movable elements that are connected by flexible elements. Only additive manufacturing offers the freedom of design to manufacture the lid. A conventionally manufactured lid with similar functions would require the designer to split the part in many simple parts and assemble them afterward.

## 6. Conclusion

Additive manufacturing's cost advantage over conventional plastic processing at low lot sizes allows more plastic products for niche markets and individualized products. Snap-fit joints proved to be a simple and cheap method of joining for plastic products. This contribution analyzed the possibilities and restrictions of additive manufactured snap-fit joints. Different potentials for the two main user interactions joining and release have been identified. Conventionally designed snap-fits showed little room for improvement in the joining mechanism while release mechanisms will benefit significantly from the ability to create more sophisticated kinematics.

The restrictions of additive manufacturing derive mainly from the anisotropy of mechanical properties and the staircase effect on the surface of additive manufactured parts. The anisotropy may reduce the durability of load bearing features while the stair stepping hinders the movement of sliders, control rings and other kinematics. To incorporate these restrictions in the design one has to determine the build direction of the part at an early design phase. Based on this decision the designer is able to design the part with respect to the properties of the selected additive manufacturing technology. In addition to this general recommendation a few guidelines were presented.

A showcase illustrates how additive manufacturing's capabilities change the way to integrate snap-fits into a part. This example is intended to inspire designers to add new functions to their snap-fit designs and respect the specific properties of additive manufacturing.

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