

OPTIMIZATION OF SNAP-FIT DESIGNS WITH RAPID PROTOTYPE TECHNOLOGY SUPPORT

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This article is focused on the design of demountable joints that have to meet high safety requirements. In total two snap-fit geometries were designed in two, respectively three modifications. These constructional solutions could be divided into two categories (easily deformable mounting elements and mounting elements deformable with difficulty). Several evaluating criteria were chosen. The most important ones were adequate strength, tightness and reliability of the resulting joint. Geometry of the snap-fit has to be also easy demouldable from the production tool and also manufacturability have to allow maximum user comfort during the assembly process. Optimization of snap-fit geometries was performed with utilize of numerical analysis and for the evaluation the prototypes created by 3D printing technology were used.

KEYWORDS

snap-fit, demountable joints, assembling, plastics parts

1. INTRODUCTION

Joining of plastic components remains still an actual issue due to wide use of polymeric materials. In recent years, primarily integrated mounting elements have been developed. These elements are dominant parts of the assembly components and they provide mutual assembling ability of individual members of the final body [Camillio 2014, K Billal 2014]. The integrated design minimizes costs and requirements for additional machining operations or for the use of additional fasteners such as screws and rivets, which belong among the most frequently selected methods of demountable and permanent jointing of badly gluable and weldable materials [Goteti 2006, Staller 2005]. The low production costs are another advantage of the snap-fit joints and that is why these elements can be used also for the production of parts in small series. Generally, the snap-fits are defined as construction elements with interaction features. They provide several functions and for this purpose their geometry must be adapted [Staller 2005, Bonenberger 1998, Genc 1998]. The main parts of the snap-fits must create an effective interlock fitting. The mounting elements used for demountable joints should be flexible enough to be able to deform elastically even in minimal workspace. Integrated mounting elements are almost not limited from the design viewpoint and the only requirement is to provide desired performances. The snap-fit joints are designed either as fixed connections or they may be able to transmit rotary motion. From the producing viewpoint the main requirements are put on the demoulding ability of the part from injection mould [Crangulescu 1997, Chow 1977]. When the design of the snap-fit is too complex then the injection mould must include mechanisms like movable cores and sliders which are expensive and difficult to maintain. The mounting elements are integral parts of the final products and that is why their design must be elegant and not disturbing the final appearance of the product. From the design point of view, a simple geometry is the best. Such a design does not increase substantially material consumption during production of the parts with integrated mounting elements. This geometry must also

minimize the possible failure of the snap-fit joint due to the complexity of the assembling operations.

Except mounting elements the snap-fit can include constituents that ensure mutual centring of assembling parts or can be dimensioned so that they prevent positioning of the assembling parts in a wrong orientation. The mounting elements or the elements that ensure centring of assembling parts can be also used for elimination of excess degrees of freedom at the contact interface [Genc 1998]. The joints are designed as demountable or permanent (separable or nonseparable). The main difference is in the response of the joint to the applied external load. Separable joints have a limited ability to withstand external stress and the strength of the connection may be reduced even when the parts are elastically deformed. On the other hand the non-separable joints withstand the external load until the mounting elements are plastically deformed. The resistance of the snap-fit connection can be predicted using a finite element analysis [K Billal 2014, Crangulescu 1997, Chow 1977]. The assembling process has various progressions. From this viewpoint two categories can be distinguished. First category includes sliding snap-fit systems (plugs) and the second one represents the bayonet-type mechanisms where a rotating movement is necessary to realize for assembly completion. Generally, the latches or clips (hooks) of various designs are the basic mounting element types and their counterparts have geometry of holes, locks, undercuts or recesses [Camillio 2014, K Billal 2014]. Suggested snap-fit joint geometry must be based on the final product function to avoid spontaneous disassembling caused only by using of the product. Snap-fit joints belong among the most frequently used demountable ways to join plastic parts mainly for opportunity to combine different materials with poor cohesion. Unlike screw connections the snap-fits are not limited by rotating geometry. Another disadvantage of threaded joints is a difficult removability from the tool during manufacturing process. That is the problem particularly of internal threads. The manufacturability is also complicated by the demand of high precision of thread profile.

Final tightness and properties on the interface of two plastic parts connected by snap-fits are strongly influenced by used material. Considering a wide range of plastics that are available nowadays, the suitable polymer material is chosen in dependence on the requests induced by the individual character of the application and possible limitations of the geometry. Favourable processability, high flexibility, sufficient strength and rigidity, low coefficient of friction and relatively high elongation are the most profitable properties of thermoplastics applicable to snap-fit connections. Other important selection criteria for the choice of suitable polymer are minimal tendencies to creep and high dimensional stability over relatively wide range of temperatures to avoid decrease of tightness caused by shape deformations (shrinkage and warpage). Polymer should withstand the humidity and the action of ambient environment to minimize the swelling effect that also causes shape and dimensional deviations. For special applications used material must resist to specific agents and chemicals. The final snap-fit design is closely linked with the acceptable strain which is the dominant material attribute from the mounting elements dimensioning point of view.

This article is focused on the design of demountable connections usable for personal protective equipments which are characterized primarily by their reliability. As previously mentioned, geometry of the mounting elements is almost unlimited therefore it is relatively difficult to compare them. For the purposes of this study the snap-fit designs were chosen which ensure sufficiently strong and tight connection with easy and intuitive assembling and disassembling and with easily producible geometry (demouldable). In the first step the suitable polymer material was selected that had to have proper mechanical properties and had to be compatible with LSR (medical type of liquid silicone rubber) which was the individual requirement. Considering the character of optimized snap-fit joints, the Nylon 6.6 (stiff material) and PP (tough material) were chosen. The concrete optimizing process consisted in shape modifications of primarily designed joints based on the results of numerical analysis reached for selected materials. Individual designs were also evaluated

in terms of manufacturability and applicability in a limited space that is available for creating of connection. Other evaluated factors were the complexity of assembling and disassembling (time-consuming, centring both parts into corrects position for assembling), material consumption (final price of the product) and the strength of connection (tendency to failures). The uniformity of distribution of contact force was also assessed for each geometry that is particularly important for guarantee of sufficient tightness in the contact surface of connected parts. The prototypes created by 3D printing technology were used to verify the functionality and reliability of designed snap-fits constructions under real conditions. The Objet Connex 500 was used for prototyping production. This machine is based on the technology PolyJetMatrix that is modified for processing of liquid photopolymers curable by UV rays. The Objet Connex 500 is a multi-material 3D printer that can combine two different types of photopolymers and their combination ensures a wide range of final material properties. The individual layers may have a thickness of 16 or 30 micrometers for one-component material. The final product is either very accurate with high quality surface or the product building is faster however the surface details are not so precise. For two-component material the applicable layer thickness is only 30 micrometers. Considering the acceptable strain the VeroWhite material was selected that has very similar mechanical properties as Nylon 6.6. For building of easy deformable snap-fit prototypes this basic material was modified by flexible component TangoBlackPlus in such a ratio that ensured the PP-like behaviour of the final mixture.

2. PROPOSED DESIGN SOLUTIONS

The only design limitation is too complicated geometry relative to production technology. Complex shapes with undercuts complicate demoulding of the product from the tool. In such a case the injection mould must include movable elements like sliders or movable cores that are expensive and tend to be damaged. Suitable snap-fits for subsequent modification were identified during background research and chosen geometries belong either to category including easily deformable elements or to elements that are only minimally deformable during assembling operation. The placement of mounting elements is also an decisive factor in addition to their geometry and dimensions. The leakage test was performed using water. With respect to capillary forces it is more difficult to ensure sealing in the contact interface against passage of water than the passage of air. The tightness was assessed in planar contact surface.

2.1 Deformable interlocking systems

Designed interlocking system employs deformable elements with construction that is not so demanding for optimizing aimed to creation of desired connection. In this variant of snap-fit connection the removable parts of the assembly have the mounting elements shaped as local negative overlaps that are distributed in the way that they circumscribe the mounting edge of the assembly fixed part (see Fig. 1). The shape of the mounting flange on the fixed part is based on essential geometric shapes (circular or rectangular) that simplify the demoulding process and assembling operations.

Mutual cohesion of joined parts is determined by the geometry of the mounting elements (clips). The support construction of clips is not perpendicular to the contact and sealing surface but the opposite clips are convergent towards their top. The heads of mounting elements provide the maintenance of the pressing force and they prevent spontaneous disassembling of the parts. The wider the mounting heads and the smaller distances among the tops of heads are the stronger forces can be transferred by the joint. On the other hand the higher disassembling forces must be applied. Assembling (disassembling) forces are applied again in the normal direction to (from) the sealing and contact surface. The outer geometry of the mounting heads is also designed as centring surface that guides both parts in optimal position during assembling process. Progression of clip deformations again requires the use of tough material especially on the side of removable part. On the contrary

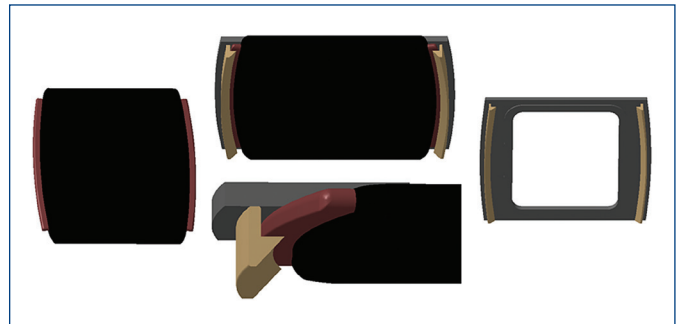


Figure 1. Deformable interlocking system

the mounting elements on the fixed part of the assembly including the flange are preferably made of rigid polymer.

2.1.1. Evaluation:

Described interlocking system has a suitable geometry to create an efficient demountable connection which primarily results from the shape of mounting elements (clips and heads). At the beginning of the mounting process the heads act as centring elements that guide both parts of the assembly in correct position. Location of clips into shape of an ellipse is particularly preferred. Such a placement minimizes the risk of excessive deformations of clips caused by poor positioning of parts during assembling operation. Mounting elements were modified for the purpose of optimization of final properties on the connection interface. The original variation of snap-fit geometry was based on a large stiffness of deformable elements. The stress distribution on the deformable elements surface and the range of maximum deformation during assembly process were identified using numerical analyzes. The Fig. 2 depicts the distribution of stress fields and the Fig. 3 shows the level of the deformation. The rigidity of

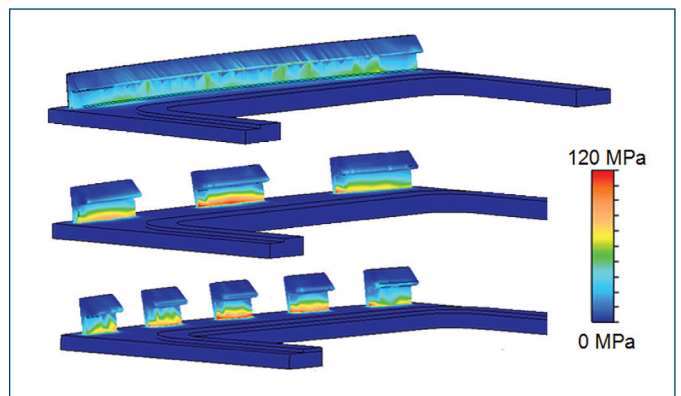


Figure 2. Stress analyzes of deformable interlocking system

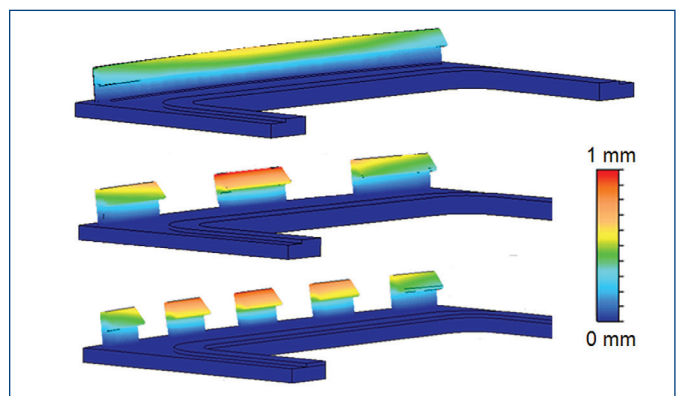


Figure 3. Displacement analyzes of deformable interlocking system

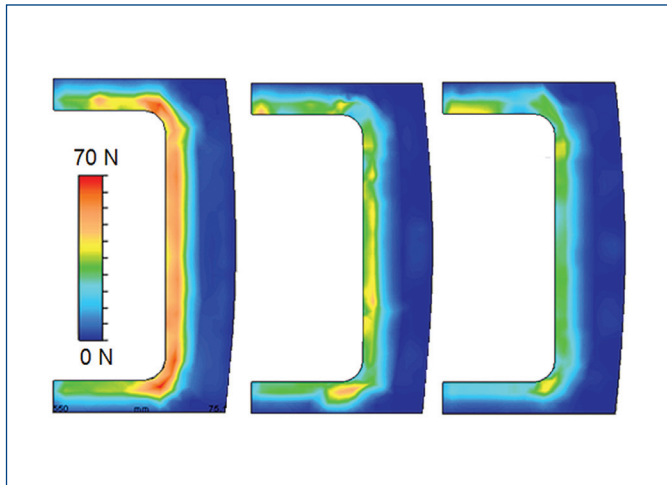


Figure 4. Reaction forces analyzes of deformable interlocking system (left 1 segment, middle 3 seg., right 5 seg.)

originally designed deformable element ensured uniform distribution of stress fields and very low values of deformation. Reaction forces belong also among outputs reached from completed analyzes and they are proportional to the total mounting forces. Identified reaction forces imply the need to use a relatively high assembly and disassembly forces in the case of first variant, see Fig. 4 (left). With respect to maximum user comfort during the assembly and disassembly operations two geometry modifications of mounting elements were designed that should reduce the required mounting force. The geometry modification consisted in section of original profile into three respectively five flexible segments. The numerical analyzes were carried out again to determine the distribution of stress fields and maximum deformation. The smaller elements formed a demountable joining, the lower rigidity was observed. The maximal resulting reaction forces caused by the assembly process were reduced by 59% in the variant with three deformable segments and by 65% for the variation with five segments. Higher flexibility of deformable elements induced higher levels of stress and led to greater deflections that were for both modified variants approximately equivalent, see Fig. 2 and 3. The distribution of reaction forces on the connection interface was the last comparative criteria. Considering the requirement for maximum tightness in the contact zone the uniform distribution of acting forces should be achieved. The highest contact forces were observed in the first case, the variant with the highest stiffness of the deformable elements, see Fig. 4. The contact forces decreased after the section of the mounting element into three, respectively five segments. The variant with three deformable segments indicated still acceptable distribution of reaction forces in the contact surface that was ensured by the placement of the clips around the connection interface. The proposed construction modifications also facilitated demoulding of the part from the tool which is probably the biggest weakness of this system. When using more extensive dimensions of clips (larger contact surface of the heads) it may be necessary to employ some special mechanism for demoulding operation (moveable cores, sliders etc.). If the length of the clip is approximately 2 mm or the clip is divided into more individual blocks so the part can be demoulded in a standard way. The assembling operation is intuitive and very fast.

3. MOUNTING ELEMENTS DEFORMABLE WITH DIFFICULTY

Materials used for mounting elements deformable with difficulty must prove highly stiff and they are mainly used for both parts of the assembly. The mounting elements are elastically deformed in a significant way neither during assembling operation nor during disassembling. From the economic point of view the next possibility is to combine the

materials used for production of individual parts. Tough material can be used for removable parts and material with higher stiffness can be used for fixed parts of the assembly.

3.1 Plug-in system

Plug-in systems belong among the simplest jointing systems. The design solution includes centring and pressing elements on the fixed part of the assembly with extended input area for easy guiding of removable part into operating position. The removable part is fitted with two slides, see Fig. 5. Both slides have a reflected orientation with protruding dots or

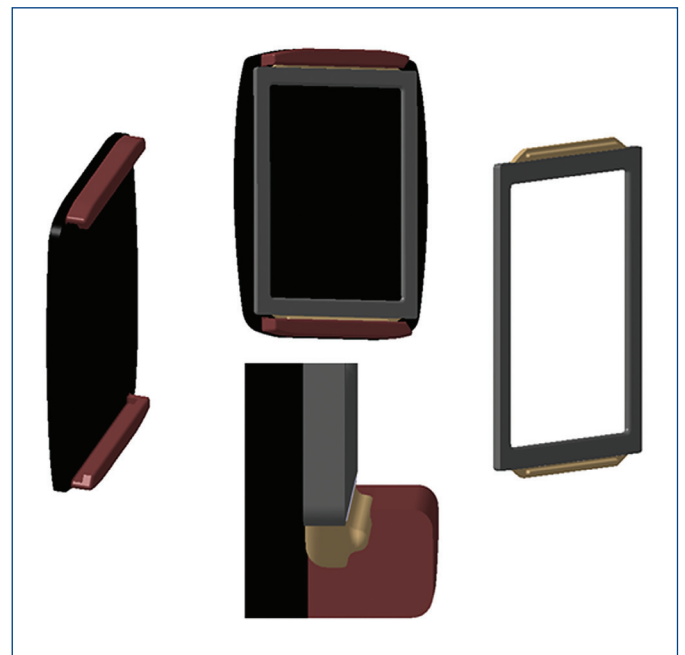


Figure 5. Plug-in system

lines in the middle. The main function of these protruding profiles is to develop desired pressing force and to ensure required tightness in the connecting interface. This snap-fit variant is very responsive to flatness of contact surfaces of both parts with respect to entirely different direction of acting assembling and disassembling forces. Used material must have sufficient stiffness for all mounting elements.

3.1.1. Evaluation:

The plug-in system provides a very precise fitting and centring of both parts of the assembly without need to add some other positioning elements. Relatively high assembling and disassembling forces are caused mainly by the friction in the interface area. The plug-in demountable joint was also analyzed in terms of the reaction forces and

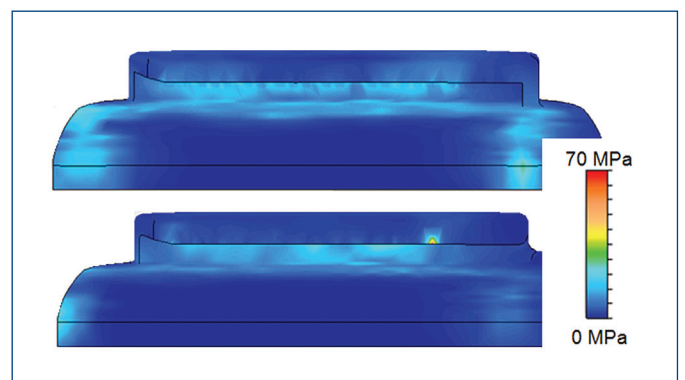


Figure 6. Stress analyzes of plug-in system

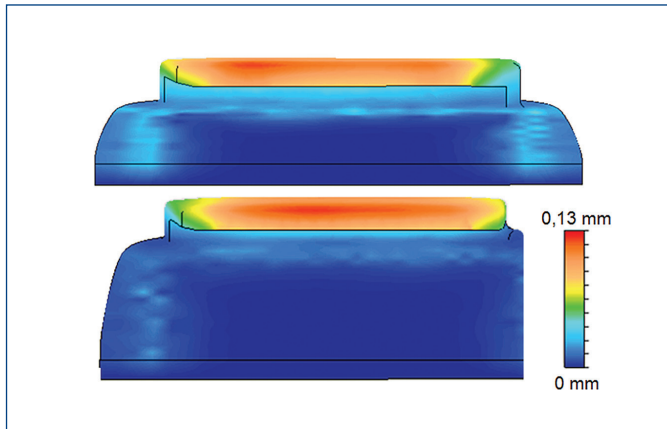


Figure 7. Displacement analyzes of plug-in system

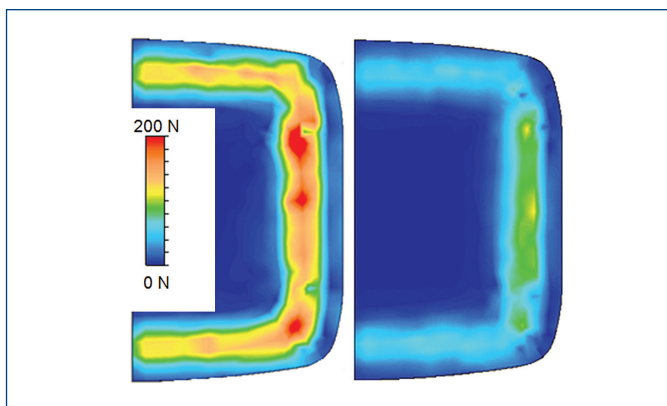


Figure 8. Reaction forces analyzes of plug-in system (left fully closed, right open-side)

stress fields distributions and determining of maximum deformation. This geometry of mounting elements was also designed in two variants (fully closed variant and side-open variant). The distribution of stress fields and the total deformations were very similar for both modifications of plug-in connections, see Fig. 6 and 7. The release of sidewall decreased the stiffness of the assembling elements which is particularly apparent from the analysis of the reaction forces in the contact zone. The values of forces ensuring the final tightness were reduced by approximately half of the original (fully closed) plug-in system, but they are still comparable with the values obtained from the same analysis performed with the deformable elements, see Fig. 8. The slides and grooves must be dimensioned optimally to guarantee creation of required and tight joint whereas orientation of the mounting elements can be optional. The longer the grooves and the more protruding profiles on the sliders are used the more homogeneous distribution of pressing force on the contact surface is achieved and the higher assembling and disassembling forces must be

applied. Disadvantage of this variant is possible damage to the contact surfaces during assembly operation caused by abrasive particle in the sealing interface that may lead to reduce of tightness in the contact area. The manufacturability of mounting elements is problematic. The geometry of the grooves in combination with stiff material prevents easy demoulding of the part from the tool and generates a demand of employment movable cores and sliders that increase the production tool in price. From the technological and user comfort point of view the open-side variant is more suitable.

4. CONCLUSIONS

Demountable snap-fit connections that can be employed for joining parts of personal protective equipments must meet very high expectations especially in terms of reliability and tightness of created connection, see Fig. 9. Two basic geometries of snap-fit joints were discussed and evaluated in this paper (three variants with easily deformable mounting elements and two variants with mounting elements deformable with difficulty). In the terms of progress of assembling operation the joints created by easily deformable mounting elements are completed by acting the mounting force in normal direction to the contact interface. Joints created by mounting elements deformable with difficulty are completed by mounting force oriented parallel to the contact and sealing surface. The centring of both parts of the assembly with plug-in system is solved by the geometry of mounting elements but used mounting force must be relatively high. On the other hand deformable interlocking system excels by the smooth and simple assembling process especially with employing more individual mounting segments. Tightness and rigidity of the connections were found sufficient for all proposed joint designs. Higher assembling forces had to be applied in cases of systems with mounting elements deformable with difficulty. The reason is the plug-in jointing geometry that induces the greatest mounting resistance. The manufacturability was one of the most important factors for evaluation of proposed designs. Final plastics parts will be produced by injection moulding technology which means that the design should be easy demouldable. From this point of view the easy deformable mounting elements are more suitable because they can be removed from the tool without additional mechanisms. For demoulding of more complex shapes and geometries (grooves and undercuts of mounting elements deformable with difficulties) the moveable cores and sliders must be employed. The differences in consumption of material among individual design solutions were not dramatic and they would have only marginal impact on economic balance of bulk production. This factor strongly depends on the type of used polymer. The best results according to final ratio of considered criteria were performed by deformable interlocking systems consists of more individual segments.

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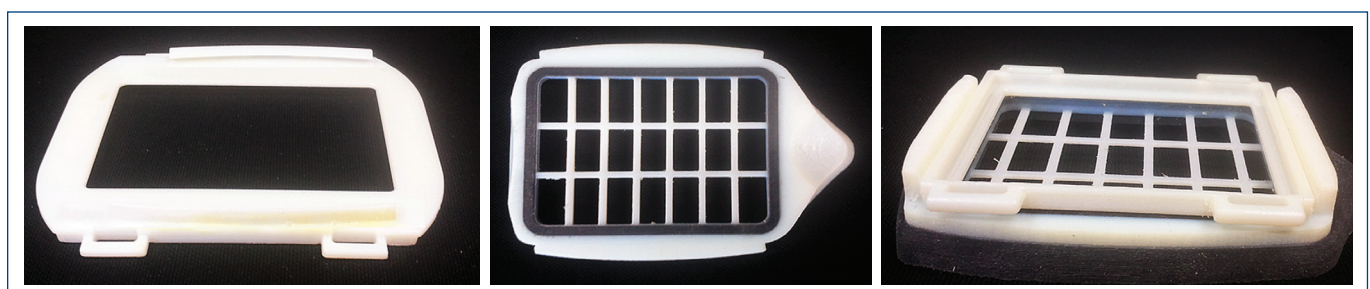


Figure 9. Prototypes of chosen snap-fit assembling created by 3D print

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