Metadata of the chapter that will be visualized in SpringerLink

Book Title	Machine and Industrial Design in Mechanical Engineering
Series Title	
Chapter Title	Application of Techniques and Systems for Additive Manufacturing in Rapid Tooling
Copyright Year	2022
Copyright HolderName	The Author(s), under exclusive license to Springer Nature Switzerland AG

Corresponding Author	Family Name	**Popovic**
	Particle	
	Given Name	**Marko**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	Gorenje MDM
	Address	Kosovska 4, 34000, Kragujevac, Serbia
	Email	marko.popovic@gorenje-mdm.com
Author	Family Name	**Mandic**
	Particle	
	Given Name	**Vesna**
	Prefix	
	Suffix	
	Role	
	Division	Faculty of Engineering
	Organization	University of Kragujevac
	Address	Sestre Janjic 6, 34000, Kragujevac, Serbia
	Email	
Author	Family Name	**Delic**
	Particle	
	Given Name	**Marko**
	Prefix	
	Suffix	
	Role	
	Division	Faculty of Engineering
	Organization	University of Kragujevac
	Address	Sestre Janjic 6, 34000, Kragujevac, Serbia
	Email	

Abstract

The paper presents the integrated application of additive manufacturing and reverse engineering technologies for the rapid tooling for two-component plastic casting, as a faster and cheaper approach than injection moulding, particularly for small-scale production of plastic parts or spare parts when CAD models and technical documentation are not available. An optical scanner based on white structured light was used for 3D digitalization of the selected plastic gas handle. Based on point cloud, a master CAD model was prepared for the design of casting tool cavities. The design of the master model was verified through its additive manufacturing using FDM technology. After repeated 3D digitization of the printed master model and comparison with the original part, the master CAD model was redesigned. The process of two-component casting in tools obtained by additive FDM manufacturing was realized successfully and verified by comparing the cast and original gas handle.

Keywords (separated by '-')	Rapid tooling - Additive manufacturing - FDM - 3D digitalization - Two-component plastic casting

Chapter 56
Application of Techniques and Systems for Additive Manufacturing in Rapid Tooling

Marko Popovic, Vesna Mandic, and Marko Delic

Abstract The paper presents the integrated application of additive manufacturing and reverse engineering technologies for the rapid tooling for two-component plastic casting, as a faster and cheaper approach than injection moulding, particularly for small-scale production of plastic parts or spare parts when CAD models and technical documentation are not available. An optical scanner based on white structured light was used for 3D digitalization of the selected plastic gas handle. Based on point cloud, a master CAD model was prepared for the design of casting tool cavities. The design of the master model was verified through its additive manufacturing using FDM technology. After repeated 3D digitization of the printed master model and comparison with the original part, the master CAD model was redesigned. The process of two-component casting in tools obtained by additive FDM manufacturing was realized successfully and verified by comparing the cast and original gas handle.

Keywords Rapid tooling · Additive manufacturing · FDM · 3D digitalization · Two-component plastic casting

56.1 Introduction

The integration of virtual engineering (VE) technologies is the best support for concurrent engineering approach because they can be of great use to engineers in making decisions and establishing control over the product development process and its production. Although they belong to relatively new technologies, they are characterized by a large number of advantages, but the key ones are reflected in the reduction of time and costs of product development [1]. One of the most significant VE technologies is additive manufacturing (AM) which is defined as the process of 3D fabrication of a part directly from a CAD model, usually layer by layer, as

M. Popovic (✉)
Gorenje MDM, Kosovska 4, 34000 Kragujevac, Serbia
e-mail: marko.popovic@gorenje-mdm.com

V. Mandic · M. Delic
Faculty of Engineering, University of Kragujevac, Sestre Janjic 6, 34000 Kragujevac, Serbia

M. Rackov et al. (eds.), *Machine and Industrial Design in Mechanical Engineering*, Mechanisms and Machine Science 109,
https://doi.org/10.1007/978-3-030-88465-9_56

497697_1_En_56_Chapter ☑ TYPESET ☐ DISK ☐ LE ☑ CP Disp.:13/10/2021 Pages: 9 Layout: T1-Standard

opposed to the method of subtractive manufacturing. AM technologies have been developed to such an extent that, in addition to rapid prototyping (RP), they also enable rapid tooling (RT). Tools made in this way enable effective application for the small-scale production of products or spare parts, especially in situations where the production of tools by conventional procedures would be extremely expensive [2].

Today, a lot of papers can be found in the literature, which through practical examples show the advantages of applying additive production technologies for fast tool making. 3D RP technology was applied to make a master model of the implant, which was later used to form a silicone rubber mold for vacuum casting [3]. Also, authors showed that the RT technology can be used very successfully in the process of precision casting of metal implants, where the tool manufacturing time is significantly shorter, and the production costs are twice lower than conventional methods. Len-Cabezas et al. [4] in their work used Stereolithography (SLA), Selective Laser Sintering (SLS) and PolyJet technology to prototype plastic injection moulding tools. The obtained tool prototypes have been successfully used for injection moulding in the production of small series using conventional polymeric materials such as polypropylene and ABS plastic [4]. The possibility of making tools for two-component plastic casting with PolyJet additive technology is presented through a practical example in [5], and it is noted that this method of production could become an optimal solution for small batches if the main limiting factors related to the curing process are overcome. Dongaonkar et al. [6] based on the results of 3D scanning developed a 3D CAD model which was used as input for rapid prototyping by Fused Deposition Modelling (FDM) technology, and finally concluded that the obtained prototype can be used as a master model for the casting process [6]. Four case studies of the RT concept in casting technology were presented, where it was concluded that Reverse Engineering (RE) supported by 3D digitization enables faster metrological control of shape and geometry, by calculating deviations between CAD models and 3D scanning results, i.e. the obtained cloud points [7]. Also, the integration of RE, RT and CAE (Computer Aided Engineering) technology can reduce delivery time and associated costs in the industry which contributes to the improvement of the competitive position in the market. The case study presented in [8] demonstrates the advantages and possibilities of integration of VE technologies. It has been shown that the application of VE technologies can successfully realize different phases of the product life cycle, while achieving savings in terms of time and costs of product development.

The aim of this paper is the application of additive production techniques and systems for rapid prototyping of master model and rapid tooling for two-component plastic casting. For the production of tools for two-component casting of the selected part (plastic gas handle), FDM technology was applied. In order to obtain tool cavities that correspond to the geometry of the handle, it was necessary to perform its 3D scanning to obtain point cloud from which a 3D master CAD model was modelled. In the end, the procedure of two-component casting using produced tools was realized.

56.2 Design of Tools for Two-Component Plastic Casting

For the additive manufacturing of tools for two-component casting of the selected part of the gas handle, shown in Fig. 56.1a, the reverse engineering procedure was applied to obtain a 3D CAD model of the handle. The first phase of reverse engineering is 3D digitization, i.e. the digital transformation of the collected data on the coordinates of points from the surface of the scanned object. The precision of 3D digitization is very important in the process of reverse engineering because it directly affects the quality of the resulting CAD model [9]. The accuracy of the applied David SLS-2 3D scanner is 0.1% of the scan size, or 0.06 mm. It takes a few seconds to get one scan, giving more than 1,200,000 points.

Adequate object preparation is necessary for successful 3D scanning using optical methods. Reflection can negatively affect the quality of the obtained results, so a thin layer of matting spray is applied to the scanning object as in Fig. 56.1b. Before scanning the object, the David SLS-2 3D scanner was calibrated in order to precisely collect point cloud data. The scanning object, just before the start of point cloud data collection, is shown in Fig. 56.1c. Figure 56.2a shows one scan of the handle in the scanner software editor. To get the entire point cloud, it was necessary to scan the object in different positions and views. The position of the lever was changed by manual manipulation, taking into account that the obtained scans must have common areas due to their correct positioning and interconnection. An overview of all obtained scans is given in Fig. 56.2b [10].

All noises and objects from the handle environment that were mistakenly "caught" during the scanning process, had to be removed so as not to impair the quality of

Fig. 56.1 **a** Gas handle, **b** matting gas handle and **c** 3D scanning of the handle

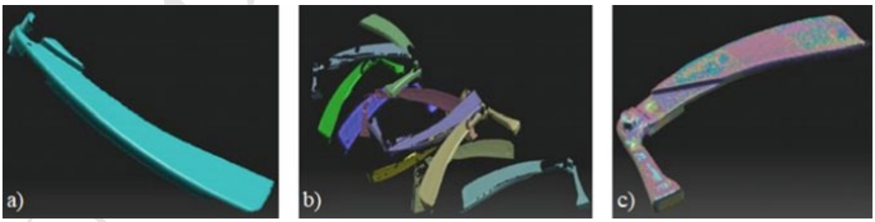

Fig. 56.2 Software processing of the obtained 3D scan results

the 3D CAD modelling. The Fusion option in 3D scanner software was used with set values for resolution and sharpness to merge all scans and form a closed CAD and STL model of the handle. By Checking the Close Holes option small holes on the resulting model was closed. The final appearance of the handle point cloud, after eliminating the noises and merging all the necessary scans, is shown in Fig. 56.2c [10].

All noises and objects from the handle environment that were mistakenly "caught" during the scanning process, had to be removed so as not to impair the quality of the 3D CAD modelling. The *Fusion* option in 3D scanner software was used with set values for resolution and sharpness to merge all scans and form a closed CAD and STL model of the handle. By Checking the *Close Holes* option small holes on the resulting model was closed. The final appearance of the handle point cloud, after eliminating the noises and merging all the necessary scans, is shown in Fig. 56.2c [10].

Due to the observed irregularities, which were caused by the inability of the optical scanner to "see" inaccessible areas and very small details, certain corrections of the 3D model were made in the CATIA software, so that the digital model had precise dimensions and closed shape. Figure 56.3a shows the observed shortcomings on the STL model of the handle, and the corrections included the reconstruction of the cylindrical supports (1), the gap between the supports and the limiter (2) and the wedge (3). Prior to the model reconstruction process, the point cloud was imported into the CATIA software using the *Digitalized Shape Editor* module. After importing the point cloud, the surface reconstruction was performed by a combination of the *Quick Surface Reconstruction* and the *Generative Shape Design* modules, using a number of useful tools. Reconstruction of critical areas, and then chamfering of edges and creation of curvature radii was performed in the module *Part Design*. Using the measuring equipment, the dimensions of the critical areas of the original handle were checked, as well as their position. The CAD model of the handle after reconstruction is shown in Fig. 56.3b.

To verify the accuracy of the geometry of the 3D CAD model of the gas handle to be used as a master model for the production of two-component casting tools, 3D additive manufacturing was performed on a MarkForged Onyx Pro 3D printer using FDM technology. Before starting the additive manufacturing process, it was necessary to set up the 3D printer, i.e. to level the printing table, which is shown in Fig. 56.4a. The STL model of the gas handle (Fig. 56.4b) was imported into the *Eiger*

Fig. 56.3 **a** Observed irregularities on STL model and **b** CAD model after reconstruction

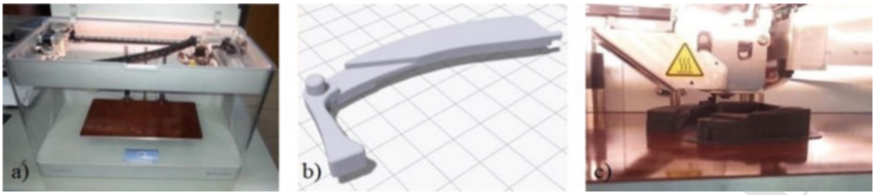

Fig. 56.4 Stages of AM process: **a** 3D printer setup, **b** STL model, **c** printed master model

virtual software library. After positioning the model on the table, the parameters of the additive manufacturing process were set. A value of 0.1 mm was selected for the *Layer Height*, and then the *Use Supports* option was activated. *Onyx* was chosen as the base material, with the *Solid Fill* option for filling the model with plastic filament. The reinforcement material was *Fiberglass*, applied with *Concentric Fiber* and *All Walls* options for 2 concentric reinforcements along all model walls.

After the completion of the additive manufacturing process of the master model, the table was removed from the 3D printer, and the printed handle from the table with increased caution in order not to damage the master model. The last step involved the removal of the support material, as well as the subsequent treatment of the model surfaces in order to remove traces of the support material and the "step effect" on the sloping surfaces. The final appearance of the master model of the handle after removal of the support material and surface treatment is shown in Fig. 56.4c.

In order to finally check the accuracy of the master model, a 3D scanning of the printed master model was performed. The point cloud (STL) thus obtained was compared with the point cloud obtained by 3D scanning of the original handle, using Geomagic Studio software. In Fig. 56.5 a comparison of the printed master model of the handle and the reconstructed CAD model is shown. It can be noticed that the deviation values of the master model in relation to the CAD model mostly range from −0.061 until +0.061 (green fields), which is considered to be extremely good results. However, higher values of deviations in the range of $-0.254 \div 0.254$ can be also considered acceptable since they are primarily a consequence of the subsequent manual processing of the surfaces of the printed handle and the rest of the support material.

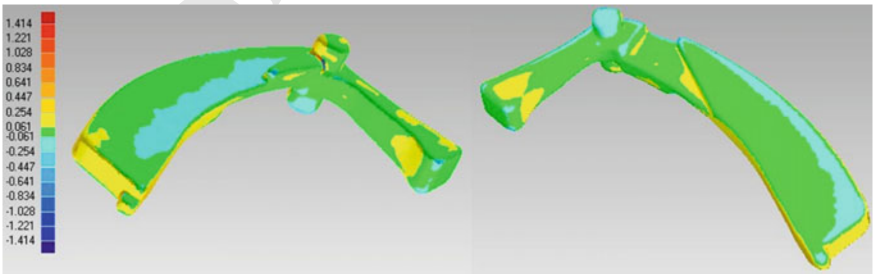

Fig. 56.5 Comparison of the master model obtained by additive manufacturing and CAD model

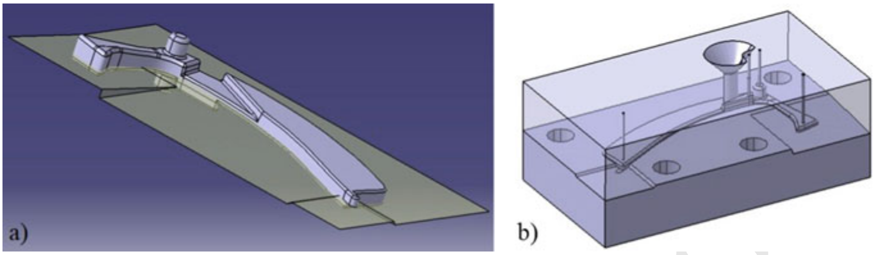

Fig. 56.6 **a** Splitting plane and **b** 3D assembly of two-component casting tool

The two-component casting tool design process included the following steps:

- determination of the split line,
- determination of overall dimensions of mold plates,
- modelling of mold cavities,
- modelling of guides, and
- selection of the appropriate location and shape of inflow channel and air vents, and their modelling.

The two-component casting tool was modelled in CATIA software. After determining the split line, a complex splitting plane was designed as shown in Fig. 56.6a. A very important step in modelling the tool was to emboss the CAD model, i.e. the geometry of the master model of the handle into the upper and lower mold plate, after which the obtained mold cavities corresponding to the geometry of the plastic casting of the handle.

The choice of the position and shape of the inflow channel is important for the casting process. An inflow channel of elliptical cross-section measuring 6×4.2 mm was chosen. In addition, at the very top of the upper mold, the channel is conically widened to facilitate the casting of liquid material into the tool.

Four guide holes, 10 mm in diameter and 10 mm deep, were modelled on the lower mold. The holes are conical in shape with a slope of 3° for easier separation of mold plates. The guides modelled on the upper mold, 10 mm in diameter and 9.5 mm high, are conical in shape with the same slope. The distance between the axes of the guide elements and the contour edges of the tool is 10 mm. The design of the upper mold also included technological openings for air in the locations of the bearing roller and in the most remote zones of the casting. The 3D assembly of the casting tool is shown in Fig. 56.6b.

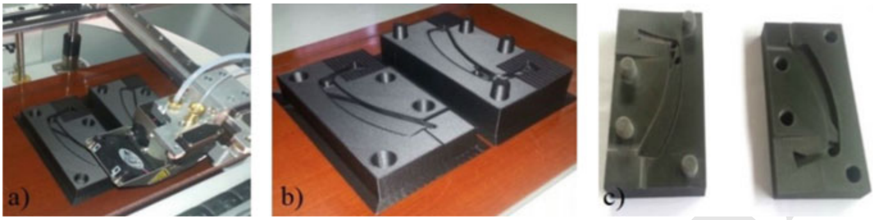

Fig. 56.7 **a** Casting molds during its additive manufacturing, **b** after removing and **c** final

56.3 Additive Manufacturing of the Tool for Two-Component Plastic Casting

Additive manufacturing of molds for two-component casting of the handle was performed on a 3D printer MarkForged Onyx Pro. The manufacturing process included all phases as in the manufacturing of master model of the handle by FDM technology. The basic material is Onyx, but unlike the printing of the master model, no fiberglass reinforcement was applied, as well as the complete filling of the tool prototype with plastic filament. The *Triangular Fill* option was chosen, which enables the creation of a ribbed structure inside the printed molds whose volume is 37% of the total volume. In order to obtain the finest possible tool surfaces, a layer thickness of 0.1 mm was chosen. According to the Eiger software estimation, it took 16 h 38 min, 103.98 cm^3 of Onyx material to make the gas handle molds, and the estimated cost of the material in the US is 24.57$.

The MarkForged 3D printer has the ability to print multiple parts on a table, so both molds are printed at the same time, as shown in Fig. 56.7a. The appearance of the two-component casting tool after the completion of the AM process and the removal of the printing table from the printer is shown in Fig. 56.7b. After removing the support material, manually treating the sloping surfaces and checking the gap in the split plane, the tool was ready for casting (Fig. 56.7c).

56.4 Two-Component Plastic Part Casting Process

The tool made by additive manufacturing technology was used during the realization of the two-component casting process, consisting of several main steps.

The first step was the preparation of the casting molds. It was necessary to inspect the molds in detail and remove all impurities that could cause various defects on the obtained castings. After that, a thin layer of separating material was applied on mould surfaces which will come into contact with the casting material, in order to facilitate the process of removing the casting from the tool.

The material used in the two-component casting process was NEUKADUR AF Neu blue, i.e. the so-called surface resin. The main feature of this material is that it has

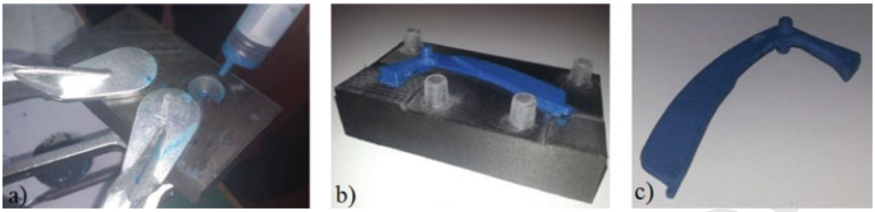

Fig. 56.8 **a** Injection of resin into the inflow channel, **b** appearance of the casting after separation of the upper and lower molds and **c** appearance of the casting after removal from the tool

great hardness and abrasion resistance. It is also characterized by improved resistance to chemicals and heat by using BWS hardeners. The casting resin was mixed with 10% of BWS hardener to give a total of 22 ml of a homogenized two-component mixture. In the next step, the mixture was injected through a inflow channel system made in the upper mold, as shown in Fig. 56.8a. After the completion of the hardening process of the mixture in the tool, which lasted about 18 h, the upper and lower molds were separated (Fig. 56.8b). The appearance of the casting, gas handle, after removal from the molds is shown in Fig. 56.8c.

56.5 Conclusions

Due to the significant advantages that characterize it, the AM technology is increasingly used, both for the rapid prototyping, and for the rapid tooling. Reverse engineering, which is defined as the opposite process to the classical process of designing and modelling of product components and tools, can be very useful in situations where there are no technical drawings, documentation or CAD models, because a 3D CAD model can be created based on 3D scanning and point cloud data.

Two-component casting in tools made by additive manufacturing process, as an alternative technology to injection molding, offers high quality plastic products with minimal costs and minimal production time, so it is suitable for small series and production of spare parts. Also, this can be useful for making functional parts that do not have excessive operating loads and special aesthetic requirements. With the application of the described methodology in the work, a plastic casting was obtained which dimensionally and functionally corresponds to the original part of the handle, so it can be used for installation in a functional assembly.

To obtain more precise parts for complex assemblies, it is necessary to apply the presented AM methodology by PolyJet technology of printing, which enables obtaining smooth surfaces of mold cavity. Optimization of the position and number of air vents can be achieved by subsequently making vents on existing printed molds. As a subject of future research, the behaviors of different casting materials in a mold made with FDM technology can be examined. This would help in choosing the most suitable mixtures of materials for performing the casting process in such molds.

497697_1_En_56_Chapter ☑ TYPESET ☐ DISK ☐ LE ☑ CP Disp.:13/10/2021 Pages: 9 Layout: T1-Standard

Acknowledgements The paper includes research conducted within the project TR34002, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

References

1. Mandić, V.: Virtual engineering (in Serbian). University of Kragujevac, Mechanical Engineering Faculty (2007)
2. Gebhardt, A.: Understanding additive manufacturing. Hanser Publishers, Munich (2011)
3. Rajić, A.: Application of additive manufacturing technologies in the process of precise casting of orthopedic implants (in Serbian). University of Novi Sad, Novi Sad (2015)
4. León-Cabezas, M.A., Martínez-García, A., Varela-Gandía, F.J.: Innovative advances in additive manufactured moulds for short plastic injection series. Procedia Manuf. **13**, 732–737 (2017)
5. Gavrilovic Z., Mandic, V., Urosevic, V.: Application of poly-jet technology in rapid tooling. In: Proceedings of the International Conference Modernization of Universities through Strengthening of Knowledge Transfer, Research and Innovation, WBCInno 2015, pp. 101–104. Novi Sad (2015)
6. Dongaonkar, A.V., Metkar, R.M.: Reconstruction of damaged parts by integration reverse engineering (RE) and rapid prototyping (RP). In: Kumar, L., Pandey, P., Wimpenny, D. (eds.) 3D Printing and Additive Manufacturing Technologies, pp. 159–171. Springer, Singapore (2019)
7. Ferreira, J.C., Alves, N.F.: Integration of reverse engineering and rapid tooling in foundry technology. J. Mater. Process. Tech. **142**, 374–382 (2003)
8. Mandić, V., Ćosić, P.: Integrated product and process development in collaborative virtual engineering environment. Teh. Vjesn. **18**, 369–378 (2011)
9. Wang, W.: Reverse Engineering. Technology of Reinvention. CRC Press, London (2010)
10. Popovic, M.: Application of techniques and systems for additive manufacturing in rapid tooling (in Serbian). University of Kragujevac, MSc Theses. Faculty of Engineering (2020)

MARKED PROOF

Please correct and return this set

Please use the proof correction marks shown below for all alterations and corrections. If you wish to return your proof by fax you should ensure that all amendments are written clearly in dark ink and are made well within the page margins.

Instruction to printer	*Textual mark*	*Marginal mark*
Leave unchanged	• • • under matter to remain	Ⓥ
Insert in text the matter indicated in the margin	⋏	New matter followed by ⋏ or ⋏ⓧ2
Delete	/ through single character, rule or underline or ⊢⊣ through all characters to be deleted	⸿ or ⸿ⓧ2
Substitute character or substitute part of one or more word(s)	/ through letter or ⊢⊣ through characters	new character / or new characters /
Change to italics	— under matter to be changed	⌴
Change to capitals	≡ under matter to be changed	≡
Change to small capitals	= under matter to be changed	=
Change to bold type	~ under matter to be changed	~
Change to bold italic	≂ under matter to be changed	≂
Change to lower case	Encircle matter to be changed	≢
Change italic to upright type	(As above)	⊹
Change bold to non-bold type	(As above)	⊹
Insert 'superior' character	/ through character or ⋏ where required	Y or ⋎ under character e.g. Y or ⋎
Insert 'inferior' character	(As above)	⋏ over character e.g. ⋏
Insert full stop	(As above)	⊙
Insert comma	(As above)	,
Insert single quotation marks	(As above)	‘Y or ‘⋎ and/or ’Y or ’⋎
Insert double quotation marks	(As above)	“Y or “⋎ and/or ”Y or ”⋎
Insert hyphen	(As above)	⊢⊣
Start new paragraph	⌐	⌐
No new paragraph	↩	↩
Transpose	⊔⊓	⊔⊓
Close up	linking ⁀ characters	⁀
Insert or substitute space between characters or words	/ through character or ⋏ where required	Y
Reduce space between characters or words	| between characters or words affected	⊤