Development of a DfAM Worksheet for Medical Casts

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INTRODUCTION

Additive Manufacturing (AM)

- Creates 3D objects by depositing material layer by layer
- Various materials for industrial applications
- Can fabricate a part with complex geometries → Mass personalization
- Fused Filament Fabrication (FFF) is a representative AM technique

Existing Studies for DfAM Guidelines

- Design for Additive Manufacturing (DfAM) prevents possible errors or mistakes in 3D printing
- Mostly require prior knowledge in AM
- Focus on AM process parameter setting values

Increasing Need of AM for Medical Casts

- Air permeability and wash-ability to prevent dermatitis
- Lightweight with high strength

Figure 1. Medical cast through AM

OBJECTIVES

Development of Cast Design Worksheet for AM

- Medical casts manufactured by AM can be freely customized for user needs.
- A practical design framework is required to provide proper design guidelines for the additive manufacturing of a medical cast at an early design stage
- This study proposes a practical DfAM worksheet for medical casts to evaluate their suitability for AM through FFF

METHODOLOGY

Step 1: Defining Criteria of a DfAM Worksheet for Medical Casts

- Key studies relevant to AM for medical casts were reviewed to extract 20 important design considerations for AM
- The common DfAM factors identified in Booth et al. (2017) were revised by considering the identified DfAM factors for medical casts
- Finally, 10 DfAM criteria for medical casts were derived and defined (i.e., Compression, Contact surface, Hole size, Hole pattern, Functionality, Strength, Tolerances, Stress Concentration, Convenience, and Material)

*Ref.: Booth, J. W., Alperovich, J., Chawla, P., Ma, J., Reid, T. N., & Ramani, K. (2017). The design for additive manufacturing worksheet. Journal of Mechanical Design, 139(10).

Step 2: Development of a Score System

- Functional score (S_f): Degree of satisfaction in user requirements and printing quality
- Operational score (S_o) : Degree of printing time and cost
- Each DfAM criterion has two or three score levels based on design characteristics defined in the worksheet
- $S_f(total\ functional\ score) = \sum f_i$ $S_o(total\ operational\ score) = \sum o_i$ (i=criterion, f=functional score, o=operational score)
- $Total\ score = w_f \times S_f + w_o \times S_o$; w_f+w_o=1 (<30 points → Redesign)

(w_f: weight of total functional score, w_o: weight of total operational score)

Step 3: Application of Proposed DfAM worksheet (Case Study)

- Perform a case study to verify the effectiveness of the DfAM worksheet
  - Subject : Undergraduate project team taking the CAD/CAM class
  - The team performed a term-project to create a medical cast design to be printed for AM
- Case study process:
  - Evaluate the initial CAD model through the proposed DfAM worksheet
  - Derive guidelines for redesign to improve low scored criteria
  - Print two samples: initially designed cast and redesigned cast
  - Compare the printing outputs (material consumption and total build time) and worksheet score
  - Conduct a user survey for the cast samples

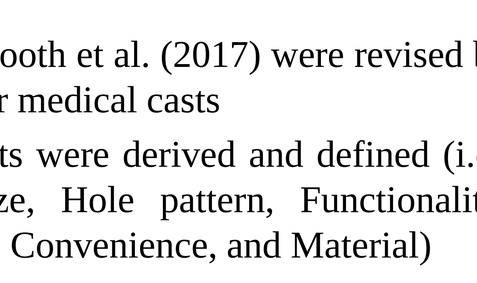


Figure 4. Initial Medical Cast Design

PRELIMINARILY RESULTS

Medical Cast Design Worksheet for AM (w_f = 0.6, w_o = 0.4)

Compression *Output will shrink and should be made slightly larger*	Functional Score	Operational Score
It is designed the size is larger than 6%	1	1
It is designed the size is 0 to 1% larger	3	5
It is designed the size is 1% to 6% larger	5	3

Contact Surface *Support is necessary for preventing sagging but not designed to contact the user's skin*	Functional Score	Operational Score
Support is required but not added	1	1
Support is made inside	3	3
Support is made outside	5	5

Hole Size *Tight hole size ex3steps it fixed but weights*	Functional Score	Operational Score
Wide hole is made in the all areas	1	5
Tight hole is made in the all areas	3	1
Tight hole is made in the parts requiring fixation	5	3

Hole Pattern *The more polygons, the weaker the durability*	Functional Score	Operational Score
Hole pattern is honeycomb	1	5
Hole pattern is grid	3	3
Hole pattern is triangular	5	1

Functionality *AM parts are light and medium duty*	Functional Score	Operational Score
Mating surfaces are bearing surfaces	1	5
Mating surfaces will move minimally	3	3
Surfaces are purely non-functional or experience virtually no cycles	5	1

Strength *Thick wall keeps holding up*	Functional Score	Operational Score
Walls are less than 2mm	1	5
Walls are 2mm to 3mm	3	3
Walls are 3mm to 4mm	5	1

Tolerances *Mating parts should not be the same size*	Functional Score	Operational Score
Hole or length dimensions are nominal	1	1
Hole or length tolerances are adjusted for shrinkage or fit	3	3
Hole and length tolerances are considered or are not important / It is all of a piece	5	5

Stress Concentration *Interior corners must transition gradually*	Functional Score	Operational Score
Interior corners have no chamfers, fillets, and/or ribs	1	5
Interior corners have chamfers, fillets, and/or ribs	3	3
Interior corners have generous chamfers, fillets, and/or ribs	5	1

Convenience *The detachable type is easy to wear and clean*	Functional Score	Operational Score
It is all of a piece	1	1
It has separating type	5	5

Material *High performance materials have high strength*	Functional Score	Operational Score
HIPS, ABS, PLA	1	5
PA, PET, PC	3	3
(CFR-)PEEK, PEI	5	1

How to assess design

1. Check the point for your CAD
2. Sum up the scores for each side and derive total score
3. Decide whether to redesign through evaluation table
4. When redesign, consider the criteria for low points

Total Functional Score (S_f) ☐ Total Operational Score (S_o) ☐

$Total\ score = 0.6 \times S_f + 0.4 \times S_o$ = ☐

10-20 | Needs redesign
21-30 | Consider redesign
31-40 | Moderate likelihood of success
41-50 | Higher likelihood of success

Figure 5. Proposed medical cast design worksheet

Case Study

Compression (*Output will shrink and should be made slightly larger*): It is designed the size is larger than 6% — Functional Score 1, Operational Score 1

Contact Surface (*Support is necessary for preventing sagging but not designed to contact the user's skin*): Support is made inside — Functional Score 3, Operational Score 3

Hole Size (*Tight hole size ex3steps it fixed but weights*): Wide hole is made in the all areas — Functional Score 1, Operational Score 5

Hole Pattern (*The more polygons, the weaker the durability*): Hole pattern is honeycomb — Functional Score 1, Operational Score 5

Functionality (*AM parts are light and medium duty*): Mating surfaces will move minimally — Functional Score 3, Operational Score 3

Strength (*Thick wall keeps holding up*): Walls are less than 2mm — Functional Score 1, Operational Score 5

Tolerances (*Mating parts should not be the same size*): Hole or length dimensions are nominal — Functional Score 1, Operational Score 1

Stress Concentration (*Interior corners must transition gradually*): Interior corners have no chamfers, fillets, and/or ribs — Functional Score 1, Operational Score 5

Convenience (*The detachable type is easy to wear and clean*): It is all of a piece — Functional Score 1, Operational Score 1

Material (*High performance materials have high strength*): HIPS, ABS, PLA — Functional Score 1, Operational Score 5

How to assess design

1. Check the point for your CAD
2. Sum up the scores for each side and derive total score
3. Decide whether to redesign through evaluation table
4. When redesign, consider the criteria for low points

Total Functional Score (S_f) 24 Total Operational Score (S_o) 38

$Total\ score = 0.6 \times S_f + 0.4 \times S_o$ = 29.6

10-20 | Needs redesign
21-30 | Consider redesign
31-40 | Moderate likelihood of success
41-50 | Higher likelihood of success

Figure 6. Assessment of case study before worksheet using

- Total score is 29.6 points : the design has to be redesigned for AM
- Although operational performance is good, redesign is required in terms of functional performance

DISCUSSION AND FUTURE WORK

DfAM Worksheet for Medical Casts

- Available to see considerations for medical cast design at once
- Objectively and quantitatively assesses the suitability of medical cast designs for AM
- Consider both functional and operational aspects in DfAM
  - Reduces wasted material and time by evaluating the CAD design before medical cast printing
  - Novices even can make casts using developed framework

Future Work

- The proposed worksheet will be improved to apply Analytic Hierarchy Process (AHP) to the evaluation process to derive the relative weights of functional score and operational score
- A redesign guideline process will be devised to provide a systematic redesign process based on the proposed worksheet
- A redesigned CAD model will be built to improve the initial cast design
  - Example:

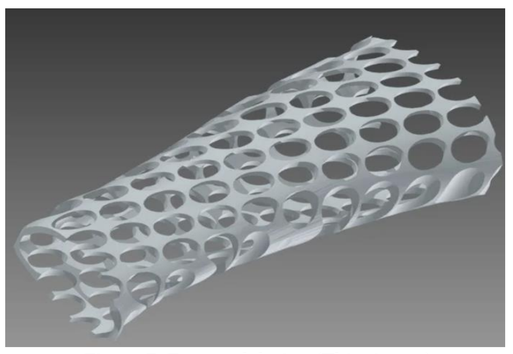


Figure 7. Expected design (Thingiverse)

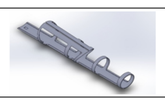
	Before Using Worksheet		After Using Worksheet	
worksheet	Total Score		Total Score	
	Functional Score	24 (Consider redesign)	Functional Score	
	Operational Score	38 (Moderate likelihood of success)	Operational Score	
Simplify 3D	Used Material		Used Material	
	Printing Time		Printing Time	
Survey				
Design				

Figure 8. Comparison before and after using of worksheet

Application

- Developed framework can be applied to a reference for developing casts that meet the needs of user and used to evaluate the existing casts