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REVIEW OF PHOTOPOLYMER MATERIALS IN MASKED STEREOLITHOGRAPHIC ADDITIVE MANUFACTURING

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Introduction

There are currently only two additive manufacturing (AM) technologies available to broader range of desktop and professional users that are not wiling to pay exorbitant amounts of money to produce their parts. These are Fused Deposition Modeling (FDM) (Chennakesava & Narayan, 2014) and Stereolithography (SLA) (Kafle et al, 2021).
FDM is also commonly known as Fused Filament Fabrication (FFF) (Singh et al, 2020).
Stereolithography was the first, original AM technology that was introduced in 1980s. Original SLA concept, still used today, uses UV lasers (Stampfl et al, 2008) to spatially solidify a thin layer of liquid photopolymer.
More modern approach is masked stereolithography (MSLA) which uses various techniques to project an entire object cross-section into the photopolymer layer (Potgieter et al, 2008).
First instance of MSLA was DLP (Digital Light Processing) SLA, where masking was provided by digital micromirror device, based on micro electro-mechanical design (Sampsell, 1994).
Second instance of MSLA is LCD (Liquid Crystal Display) SLA, and this technology is the topic of this paper. This type of MSLA uses ordinary LCD panel without any back illumination as spatial modulator for layer projection (Wu, Xu & Zhang, 2021).
LCD SLA is the dominant variant of MSLA technology. There are many contributing factors to this. Low 3D printer cost, large number of manufacturers and models, simple use, high-detail and high-speed 3D printing, low maintenance, simple machine design and a large community of users.
SLA works exclusively with thermosetting polymers (Zhang & Xiao, 2018).
SLA technology can produce only single-material parts. Only exception to this is BCN3D's VLM technology that can use two resins in the same part, but as of now has only been announced as an expensive, professional technology.
Purpose of this paper is to investigate current situation on low-cost resin market (consumer market), as these materials are the ones that are used in consumer LCD SLA 3D printers. LCD SLA 3D printers are a relatively new occurrence and therefore availability of related low-cost resins has generally trailed behind the wide range of professional materials made available for professional SLA printers from industry leading manufacturers.

Methods

It must be understood that there is almost no concrete available data on sales volume of individual consumer resin manufacturers, nor is there a clear consensus on where the distinction between manufacturers of professional and consumer resins is.
Given that there are no clear data on popularity or size of consumer resin manufacturers, it was decided to select a representable sample of manufacturers based on their popularity and reputation in user community and websites dedicated to 3D printing. Selection was further narrowed based on Google Trends search popularity over the last 12 month. In the end six manufacturers were selected. Three of those produce 3D printers and resins, while three only produce resins.
Formlabs was selected as a representative for professional side of resin manufacturers and was used as a comparison to manufacturers of consumer 3D printers and resins.

Results / Discussion

Based on initial research of user communities (Reddit/3dprinting,Quora/3D printing, 3D Hubs) and dedicated websites (All3DP, 3DPrinting, Clever Creations, TCT Magazine, 3D Insider) we identified seven most prominent companies that produce both 3D printers and resins. These are Elegoo, Prusa, Peopoly, Flashforge, Creality, Anycubic and Phrozen. Further five prominent companies were identified that only produce resins. These are eSun, Nova3D, Monocure3D, Liqcreate and Sunlu.
Google trends gives further insight into popularity of these companies. The term that was used was "name_of_the_company resin", i.e. "creality resin". Term "resin" was included as to discount results advantage that companies offering both 3D printers and resins would have.

Table 1: Relative search result share of considered companies

Company name	Offer	Rank	Relative search result share
Anycubic	3D printers and resins	1.	100%
Elegoo	3D printers and resins	2.	90%
Phrozen	3D printers and resins	3.	31.6%
Creality	3D printers and resins	4.	28.4%
eSun	Resins	6.	20%
Prusa	3D printers and resins	5.	14.2%
Liqcreate	Resins	7.	14.2%
Monocure3D	Resins	8.	12.6%
Sunlu	Resins	9.	11%
Nova3D	Resins	10.	7.9%
Flashforge	3D printers and resins	11.	4.7%
Peopoly	3D printers and resins	12.	3.1%

Material range, pricing and mechanical datasheets were collected for every company. Amount of available data in mechanical datasheets was divided into three categories: "none", "basic" and "extensive". "None" means that no mechanical data was provided.
"Basic" category contains resins for which some data was provided and this was limited to 3-6 mechanical parameters since this amount of data is sufficient to predict reasonably well behaviour of parts produced using these resins. Finally, "extensive" category was reserved for resins that have 7 or more mechanical parameters provided, meaning that it is possible to accurately predict behaviour of parts produced using those resins.

Table 2: Anycubic's resin range

Resin name	Price (USD/kg)	Mechanical data
Colored	38	none
Plant based	41	basic
Flexible tough	60	basic
DLP Craftsman	45	basic
Water-wash	36	basic
Standard	35	basic
ABS-like	38	basic
Dental	60	none
Average price:	**44.1**	

Table 3: Elegoo's resin range

Resin name	Price (USD/kg)	Mechanical data
Plant based	35	basic
ABS-like	34	extensive
Standard	29	basic
8K standard	30	none
Water-washable	34	basic
8K water-washable	40	none
Thermochromic	40	none
Average price:	**34.6**	

Table 4: Phrozen's resin range

Resin name	Price (USD/kg)	Mechanical data
Aqua 4K	40	extensive
Aqua 8K	50	extensive
Speed	38	extensive
Aqua	38	extensive
Water-washable	38	extensive
Mud-like	140	extensive
Flex	69	extensive
ABS-like	33	extensive
Castable W40	240	none
Castable W20	220	none
TR300	50	extensive
Castable Dental	200	extensive
Protowhite Rigid	80	extensive
Rigid Pro410	70	extensive
Functional TR250LV	38	extensive
Stiff	80	extensive
Tough	78	extensive
Average price:	**91.5**	

Table 5: eSun's resin range

Resin name	Price (USD/kg)	Mechanical data
eResin PLA	60	extensive
eResin PLA Pro	60	extensive
Standard	70	extensive
Water-washable	60	extensive
PM200 PMMA-like	56	extensive
Hard Tough	80	extensive
eResin Flex	120	extensive
Average price:	**72.3**	

Table 6: Liqcreate's resin range

Resin name	Price (Euro/kg)	Mechanical data
General purpose	90	extensive
Premium Flex	75	extensive
Premium Model	75	extensive
Premium Black	66	extensive
Premium Tough	75	extensive
Hazard Glow	150	extensive
Tough X	140	extensive
Strong X	160	extensive
Flexible X	130	extensive
Composite X	113	extensive
Clear Impact	130	extensive
Wax Castable	90	extensive
Gingiva mask	140	extensive
Dental model	140	extensive
Average price:	**113.8**	

Table 7: Monocure3D's resin range

Resin name	Price (USD/kg)	Mechanical data
3D Pro Bigvat	119	none
3D Pro Crystal Clear	119	none
3D Pro Deep Black	119	none
3D Pro Glow	141	none
Study	137	none
Precise	160	none
Gingiva	160	none
Tuff	121	basic
3D Rapid	55	none
Flex100	121	none
Average price:	**125.2**	

Conclusion

It is difficult to gauge entire resin market for consumer MSLA 3D printers. There are many 3D printer manufacturers offering their own resins and there are many manufacturers specialized only in resins. This paper aims to cover most notable companies in both segments and data suggests that the market situation is rapidly becoming more favourable for desktop MSLA users seeking to utilize more advanced resins at a reasonable price. Prime examples of this are Phrozen Liqcreate. Phrozen has a diverse offering of resins at a reasonable price, while Liqcreate offers rather advanced resins like Composite X, albeit at a higher price. However, it is still substantially less expansive than Formlabs's offering of high-performance materials.
Somewhat surprising is the fact that there are very few eco-friendly resins available. Apart from Anycubic and Elegoo, there are no plant-based resins from any other manufacturers considered in this paper. Desktop resin 3D printing is becoming more popular and one of the most negative aspects of this technology is the fact that resins are difficult to work with and hazardous to health. Up until recently, all resins had to be washed in isopropyl alcohol. Today, all resin manufacturers offer water-washable resins that can be cleaned in tap water. While this is much more convenient for users, these resins still present health hazard. As MSLA technology grows in popularity, development of less toxic, eco-friendly resins is of paramount importance for the users and the environment.
It can be concluded that the range of affordable priced resins is substantial, if not yet diverse like in professional SLA 3D printing. Given that MSLA 3D printing is a still a rather new technology, the outlook for further expansion of material range is good. Many of the companies offering MSLA 3D printers and affordable resins are of Chinese origin, and that has historically been viewed as a negative. However, more and more of these companies are achieving recognition in Western markets and this leads to increased sales, which in turn leads to more research and development of new resins. Therefore, the market in rapidly expanding and it will be interesting to see further developments in years to come.

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