CONTROLLED LOCAL PROPERTIES IN THE SAME PART WITH SINTAFLEX A NEW ELASTOMER POWDER MATERIAL FOR THE SLS PROCESS

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Abstract:
A new powder material for the SLS (Selective Laser Sintering) process was recently released. The material is a result of fruitful research programs involving industry and university. The well known and widely used DuraFom™ (PA12) and theCastForm™ (PS) SLS-materials were developed by the same team.
In the search for new powder materials many properties of the candidate polymer, e.g. the pulverization, the laser absorption and sintering parameters have to be tuned carefully. Previous Elastomer options materials were poor in strength, detailing, and long-term use. The new product overcomes most of the known deficits. It open completely new practices in many branches like: automotive, house appliances, office equipment, foot ware, medical, and many more. The Sintaflex has a Shore hardness variability 45-75 A and Elongation up to around 300%. The attainable yield strength range is 1.3 - 4.2 MPa. The resolution on the SLS part is up to 0.6 mm. It is positioned in good agreement compared with other commonly used injection plastics.
Furthermore, the appeal of all SFF process beside geometry and complexity is thought in varying locally the mechanical properties. Some published patents make suggestions in this direction. The new material, due to the particular properties range in function of the sintering parameter, allows first time to realize this wish. The generated part has controlled variable local properties; a new and unique opportunity opens for the SLS process.
The paper describes the basic material properties. Further the main sintering parameters are describes and indications on machine settings are given. RP (Rapid Prototyping) applications and the recent practical experience are illustrated. Distinctive examples of local variable properties in the same part and given limits are shown. Some conclusions are stated.

Keywords: Rapid Prototyping, Selective Laser Sintering, Elastomer

1 Introduction

The new SLS powder material targeted user needs. We wanted to find an elastomer covering the traditional uses. The typically used final elastic part materials are numerous; starting with natural rubber (NR), butadiene- caotchouc (BR) Nitric caotchouc (NBR) and others, a widely used material in injection molding are the Ethylene-propylene rubbers and elastomers (also called EPDM and EPM). Previous attempt to mimic flexible rubber-like materials was also considered [2]. The previous proposed solution failed due to unacceptable final part properties disintegrating and processing difficulties [10]. Nevertheless user evidenced the need and benefits, the problem remained latent [1].
This research targeted to provide alternatives. As reference properties Neoprem, EPDM, and

natural rubber in respect to elongation at break and shore hardness, both the most significant properties in thermoplastic elsatomer material selection, were considered. The final positioning of the new Sintaflex is compared in Fig. 1.
The appeal of all Layer Manufacturing (LM) processes beside speed, geometry and complexity is thought also in local mechanical properties variation. This feature is also termed gradual properties change. Some published patents make suggestions in this direction.
The new material, due to the particular properties range in function of the sintering parameters, allows first time to implement this aspiration. The generated parts may have controlled variable local properties. A new future oriented opportunity for the SLS process.

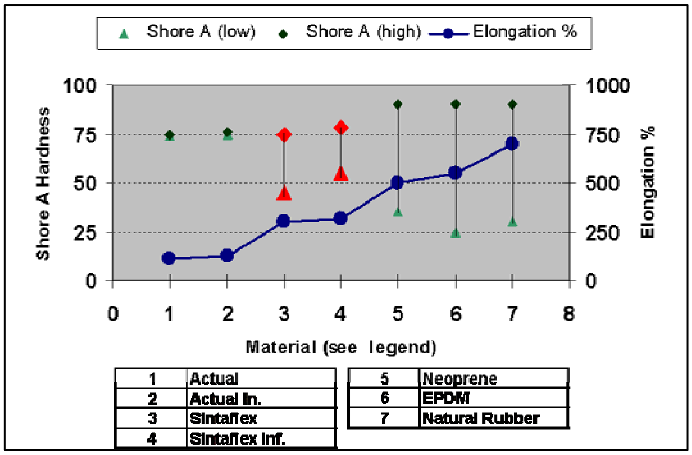

Figure 1. Sintaflex in relation to commonly used elastomers

2 Signposts in the Sintaflex research

2.1 Basic material

It needs a long evaluation and experimental work to validate and formulate a suitable SLS powder material [5]. After fulfilling the SLS process requirement the final parts have to be characterized. [3] We find always a radical weakening in the mechanical initial properties, a prediction is not possible, and the deterioration is significant. We have selected finely as basic material Polyester with Shore D 40 [Table 1] & (Fig.2).

Table 1: Polyester initial material properties

Tensile stress at break	27 MPa
Elongation at break	600%
Tensile Impact strength	145 KJ/m2
E-Modulus	172 MPa (at -40°C), 55 MPa (at 23°C), 28 MPa (at 100°C
Density	1.1
Chemical resistance	Resistance to swell in oils, aliphatic and aromatics, hydrocarbons

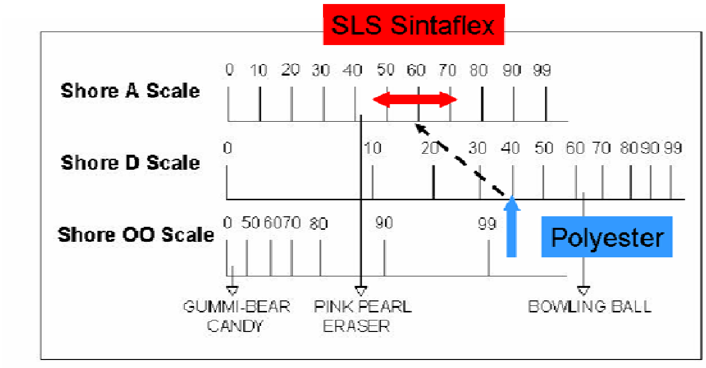

Figure 2: Initial bulk material shore hardness and the alteration after selective laser sintering

2.2 The SLS Powder

The bulk basic polymer has to be milled and formulated adding required additives to enable the use on the SLS system. The characteristics of the powder and the grain size distribution have a significant influence on the final properties. Further more, to enable tightness an infiltration seal fluid was developed and is regularly used. Parts in natural state as coming of the SLS platform can be used as well as infiltrated parts (Figures 3, 4). The infiltration is available in several colors.

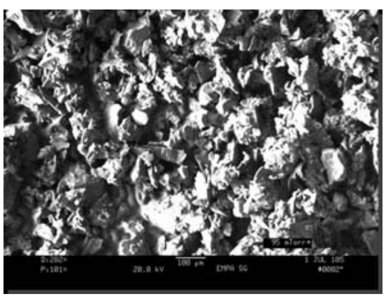	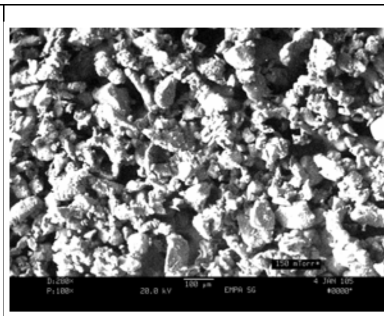	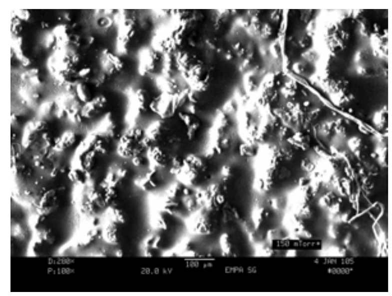
Powder	Not infiltrated sintered Sintaflex parts	Infiltrated Sintaflex parts

Figure 3. SEM pictures of the Sintaflex SLS powder/parts in various stages

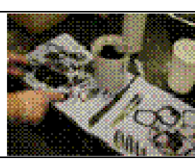	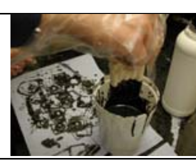	

Figure 4. The infiltration procedure

Valspar chose 3D Systems [13] to commercialize the Sintaflex and Sintafluid products under 3D's DuraForm® brand. The products will be known as:

DuraForm® Flex plastic LS Material, and
DuraForm® FlexSeal

(Black, Blue, Yellow, Red, and Neutral) infiltration fluids

2.3 Typical optimized Laser Sintering Parameters

The typical sintering parameter for a DTM 2500 plus are given in Table 2.

Table 2: SLS typical processing parameters

Build-Parameter 2500plus			
Layer Thickness	[mm]	0.1	
Part Bed Temperature	[°C]	116	
I/O Ratio	[%]	75	
L/ R Feed Distance	[mm]	0.285	
L/ R Feed Temperature	[°C]	93	
Piston Heater Temp.	[°C]	105	
Cylinder Heater Temp.	[°C]	100	
Roller Speed	[mm/min]	177	

Part Parameter			
Parts	LP	OLP	SP
	11	4	0.15

During intensive investigations we found out that the most significant parameters influencing the final mechanical part properties are the Laser Power and the Scan Space (SP).

3 Mechanical properties SLS sintered Sintaflex parts

The development process is wide-ranging and involves numerous iterations and modifications of the final product. We present here the final optimized properties. Further the influence of the major single parameter, the laser power is given in detail. This particular characteristic opens up the new opportunities.

The experiments were carried out on a 3D systems Sinter-station 2500^{+} . In a second step prior to commercialization the optimized parameters sets for all actual Sinter-station platforms were elaborated. A set of typical parameters are shown in Table 2. for orientation only.

It was found that the SP scan space has a moderate influence on the achieved mechanical properties mainly the strength (see § 5.1). The most significant properties elongation at break and shore A hardness were found to be well correlated to the laser beam power (LP) during hatching.

In order to render tightness the infiltration following process is used. We report on the infiltration later however from here on we have to consider natural parts as coming of the Sinter-station and Infiltrated part post processed. The diagrams will show the two corresponding states.

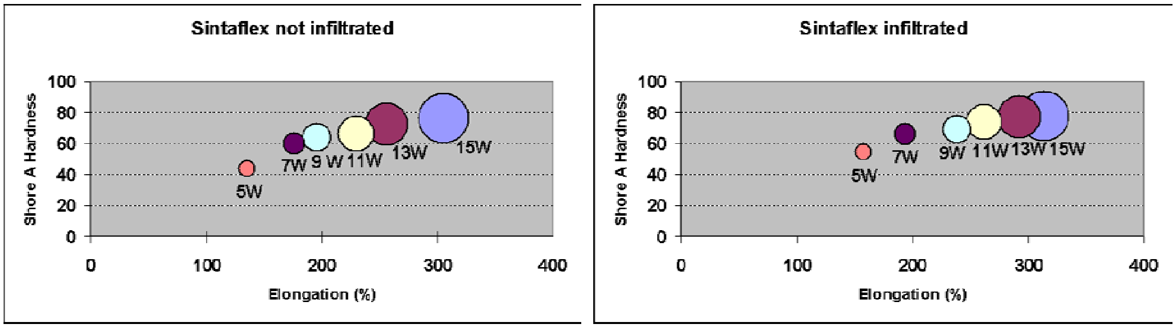

Figure 5. Hardness Shore A vs. Elongation [%] for infiltrated and not infiltrated parts

In Figure 5 we can see the shore hardness in function of the elongation with the laser beam power as parameter, the left diagram relates to not infiltrated and the right one to the infiltrated state. In both case we see a clear correlation. It becomes also apparent that we have a properties range. The Sintaflex has a Shore hardness variability 45-75 A the shore hardness, this was measured with a common durometer [4](see also Table 4).

For the hardness measurement, in accordance with DIN EN ISO 868, we use a Hildebrand a manual Durometer Model HD3000 with a Drag pointer [11]. It is very important for repeatability and proper results to calibrate the sinter system used. The laser power in operating in an open loop mode, the value on the screen mostly does not correspond to the actual real power values. The time dependent drop in laser power output may have significant uncontrolled influence on the hardness and the final part's mechanical properties.

The tensile tests were done on a Zwick testing machine according the ISO 527-2 standard. The mechanical properties E module [MPa] and the tensile strength at rupture Rb [MPa] are quasi linear with the laser power (Figure 6). The influence of the infiltration is very small. Actually from the practical point of view the differences are negligible.

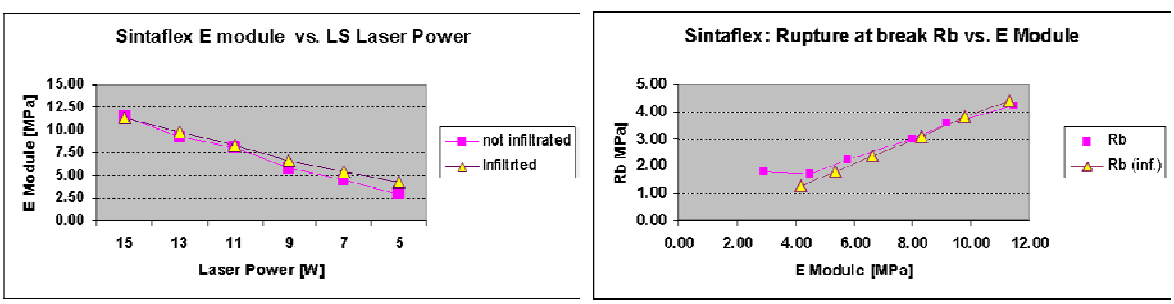

Figure 6. The E [MPa] module, the tensile strength Rb [MPa] at ruptures the Laser power [W] interrelations

4 The mechanical properties range

In summary, the Sintaflex has Shore hardness variability 45-75 [Shore A] with resultant Elongation up to around 300 [%]. The attainable yield strength range is 1.3 - 4.2 [MPa] and the corresponding E module is between 3 and 11.5 [MPa].

The geometrical resolution on the SLS parts is up to 0.6 mm. It is positioned in good agreement compared with other commonly used injection plastics (see also Figure 1). Figure 7 represents some typical parts realized with Sintaflex; many other projects were successfully implemented. [7].

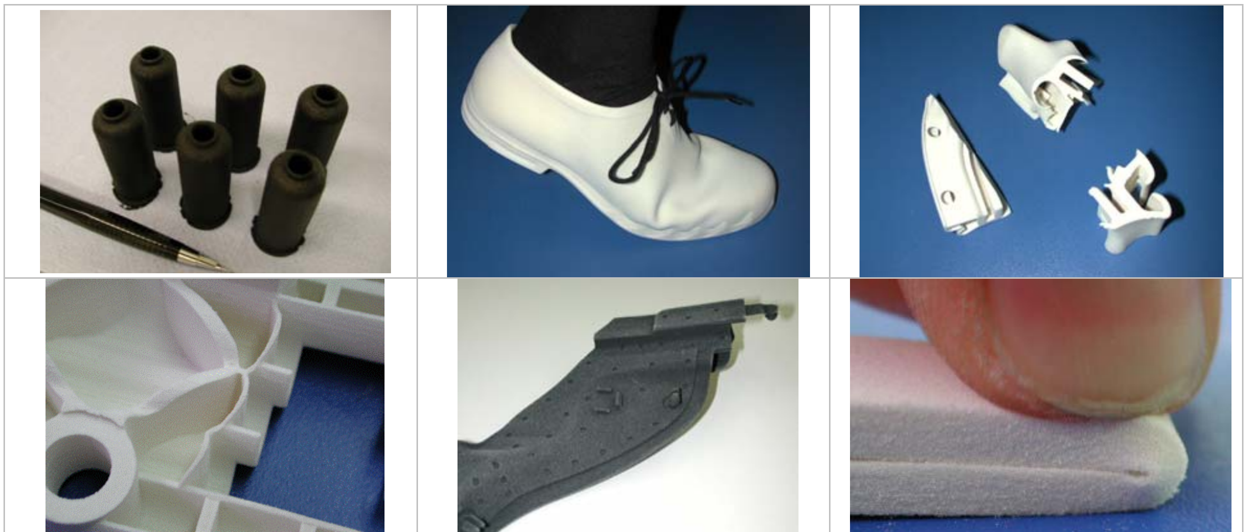

Figure 7. Some representative Sintaflex parts (white parts are not infiltrated)

The Laser Power [W] parametric variation as shown in Fig. 8, 9 and as said before, controls the main property the hardness and the resultant Elongation [%], E module [MPa] and Rb [MPa],. Combined with the following infiltration process the final properties are of practical use and concern.

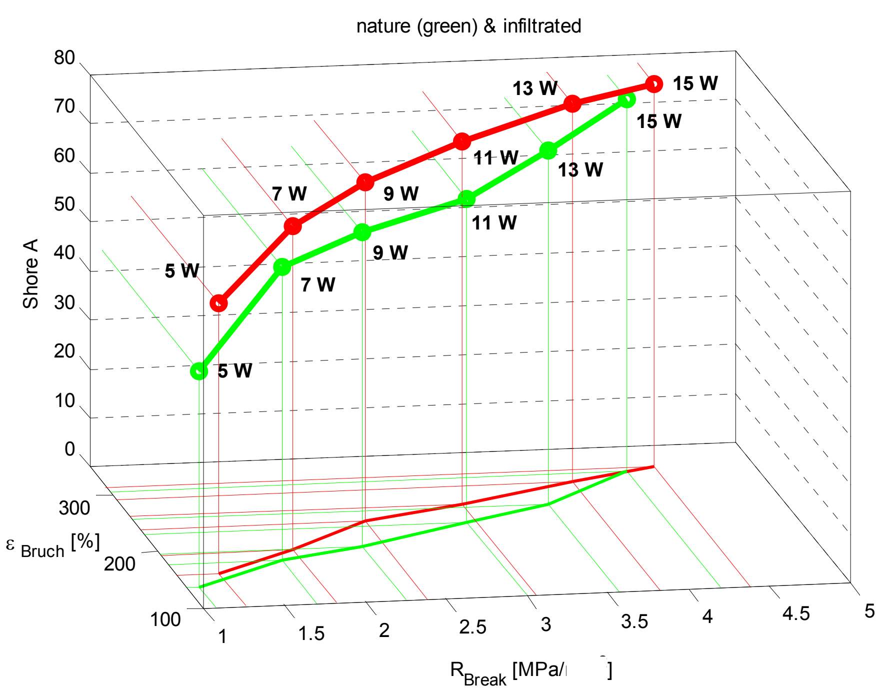

Figure 8. Hardness, Elongation and rupture tensile strength range with laser power as

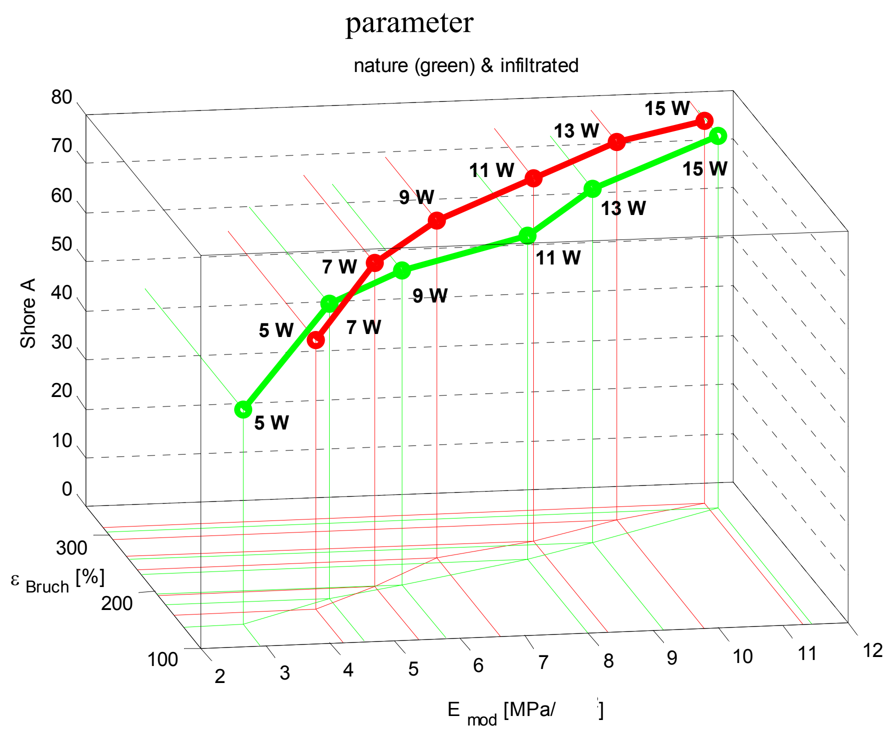

Figure 9. Hardness, Elongation and E module range with laser power as parameter

Beyond a valuable new SLS elastomer material we ended up with the first commercialized material with gradual property changeability in a part. The major variable property is the Shore hardness [A] controlled by the laser power used during the selective laser processing.

5 Layer manufacturing consistency

With the trend and wish to move further towards RM (Rapid Manufacturing,) attention has to be focused on consistent results. Some of the inconsistency results from the process nature. It is a thermal process causing in-homogeneity; it is a layering procedure creating non-isotropic material properties. In the following relevant points related to our case, specifically: material and system are briefly discussed.

5.1 Material related

The statistical variances measured are shown in Fig 10. In respect to the Rm [MPa] tensile strength and the E module [MPa] the variances are acceptable values. The shown measurements are made on the XY plane and the X direction positioned tensile bars.

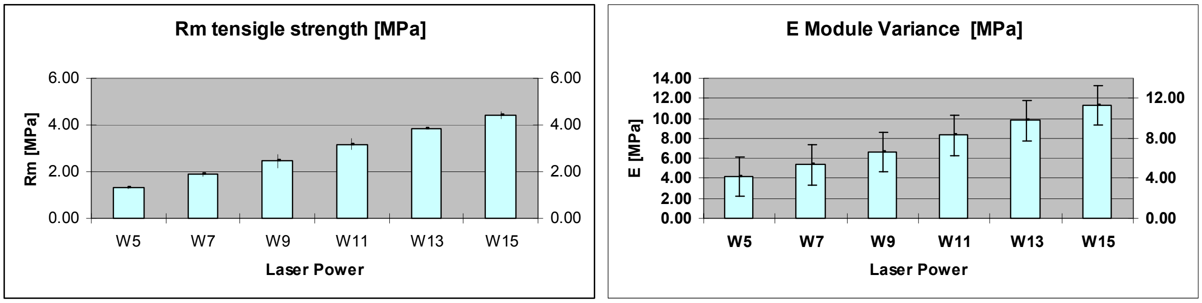

Figure 10. Rm [MPa] tensile strength and the E module [MPa] variances (XY plane; X direction)

The second important parameter after the laser power is the scan space. We compared the mechanical properties of the parts with 0.15 and 0.3 mm scan space. The standard tests show no significant differences regarding the tensile strength (Table 3).

Table 3. Zwick machine tensile testes results for Sintaflex scan spacing 0.15 and 0.30 mm

		S0	L0	Emod	Rm	RB	ε-Bruch	Rp x
		mm2	mm	N/mm2	N/mm2	N/mm2	%	N/mm2
Nature 11W Scan space 0.15 mm	**1**	40.70	60.00	7.12	2.74	2.72	237.12	0.41
	2	40.70	60.00	6.97	2.44	2.43	171.87	0.38
	3	40.32	60.00	6.95	2.66	2.65	221.83	0.40
	4	40.32	60.00	7.25	2.51	2.51	168.83	0.39
	? X	40.51	60.00	7.07	2.59	2.58	199.91	0.40
	s	0.2205	0.00	0.14	0.14	0.13	34.20	0.02
	v	0.54	0.00	1.98	5.31	5.11	17.37	3.84
Nature 26W Scan space 0.3 mm	**1**	40.96	60.00	8.86	3.14	3.12	211.82	0.46
	2	40.99	60.00	9.27	3.31	3.27	237.74	0.47
	3	40.68	60.00	9.14	2.99	2.94	163.05	0.47
	4	41.39	60.00	9.05	3.09	2.93	184.08	0.50
	? X	41.01	60.00	9.08	3.13	3.07	199.17	0.48
	s	0.29	0.00	0.17	0.13	0.17	32.56	0.02
	v	0.72	0.00	1.92	4.27	5.41	16.35	3.92

However looking at fine featured parts; in particular for thin walls < 1 mm the strain strength analysis (4mm specimen) is not significant. It is not a suitable test. The not sintered micro voids generate week points in the part (porosity) and may cause undesired part failures. Hence if one prefers consistent strength and high quality over productivity use 0.15mm scan space, the sintering time becomes longer. On the other hand if one wants fast parts with not so consistent strength you may use 0.3mm with better productivity. We recommend using 0.15 mm at all times. In any case users will have to consider the system related calibration for each case (see 5.2)

5.2 System related

The main parameter is the laser power; unfortunately the laser power deteriorates over time. We have an open loop system. Furthermore the systems have no real power indication on the control it is just a scalar number. Hence any machine with the same settings may produce different (also unwanted) part qualities.

We developed a walk around, a laser power individual machine calibration set. It consists of standard parts to be produced measured and calibrated by a software program. This calibration enables also to predict the mechanical part properties. It has to be repeated occasionally.

A seconded issue is the temperatures settings. We are dealing with a thermal process but have no real absolute temperature indications. Each individual machine has its one temperature values setting. Soft ware temperature deduction methods were implemented.

The third missing possibility in standard equipment is the gradual continuous power change in a cross section. A walk around is the subdividing of the cross section into single attached: STL files. This is only an approximation used for the application examples.

It is strongly recommended to remediate these lacunas in future systems and future work in favor of consistent rapid manufacturing applications. [6]

6 Gradual properties application example

The practical future utilization of gradual properties change in LM produced parts is an innovative challenge.
Several researchers are continuously trying to develop patient individual prosthesis using geometrical design features as main local body contact optimization parameter. In reference [8] e.g. a “Double-Wall, Transtibial Prosthetic Socket Fabricated Using Selective Laser Sintering” is proposed. The SLS process is often indicated [9].
Figure 11 described another option. The commercial foot RE (Reverse Engineering) system serves for the precise geometries capture.

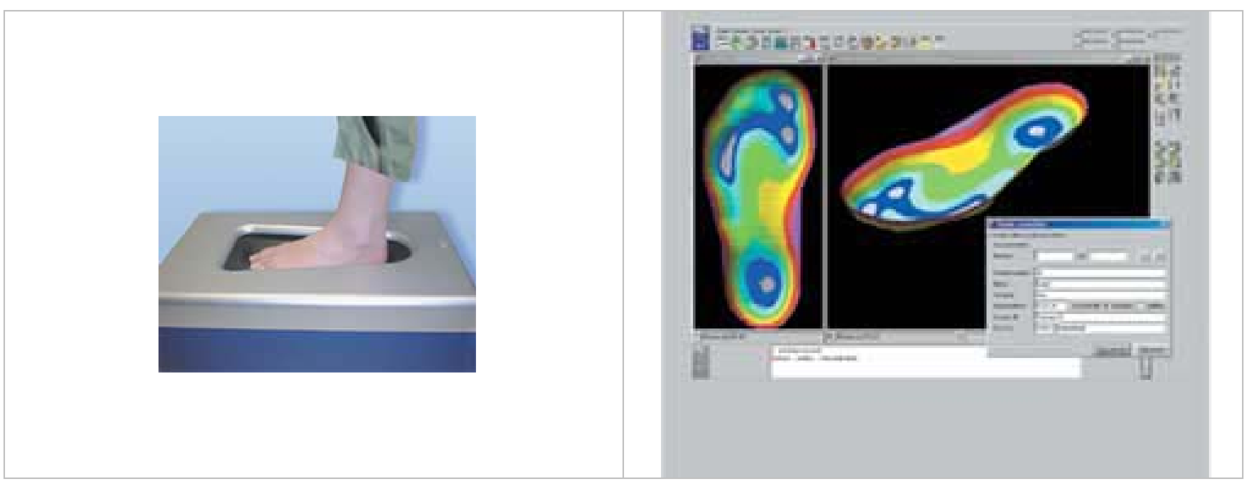

Figure 11. PED-CAD Germany http://www.pedcad.de/beginn.php3

This 3-D foot sole measuring device is a step forward. It does not measure only the foot shape precisely but it is: simultaneously during the measuring process, modeling the foot in an ideal shape [12]. The 3-D foot modeler, measures to meet medical and orthopedic technical standards.

In all similar cases we can capture in addition the pressure distribution and local stress distribution. This information can be introduced in the design for finding the best suitable local material attributes e.g. the local hardness. A complementary attribute to the geometrical features normally used. Some research projects in this direction are on the way.

6.1 A simple flat sole

In order to demonstrate its feasibility a sole was designed, divided in 5 pressure zones. To each zone a specific shore A value was attributed. The soles were laser sintered on a DTM 2500^{+} in Sitaflex with the proper hardness related laser power parameters. The infiltrated soles were measured and validated. The results are presented Table 4 and graphically in Fig. 12.

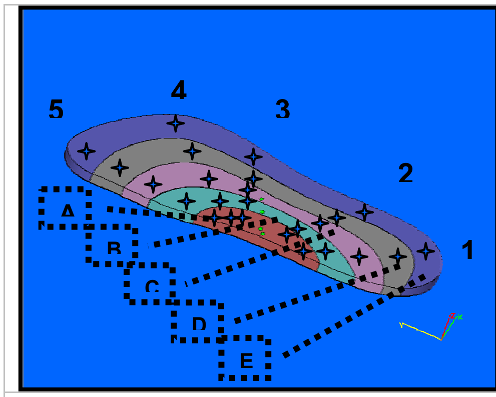

Table 4. Flat sole with locally attributed different hardness and result measurements

Zone	1	2	3	4	5	medium	Sigma	deviation
A	73	74	75	74	73	73.80	0.75	1.01%
B	70	70	71	70	70	70.20	0.40	0.57%
C	65	68	69	67	69	67.60	1.50	2.21%
D	59	56	58	55	56	56.80	1.47	2.59%
E	52	51	53	49	52	51.40	1.36	2.64%

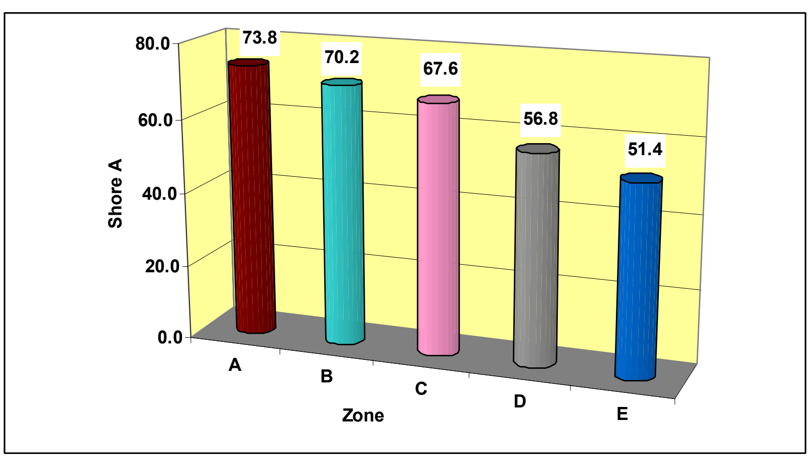

Figure 12. The shore A hardness of a sole in the zones A-E

This new material feature can consequently be applied for other mass customization or product features individualization in various branches.

7 Conclusions

A new SLS elastomer powder martial was presented. The material enables to vary locally the shore hardens in a certain range. The system limitations and some requirements for safe consistent Layer Manufacturing were stated. An example demonstrating these abilities was shown. Some equipment related modifications are recommended.
Supplementary work has to be done on the new materials level. Further system features (HW and SW) and design for layer manufacturing are compulsory. Never the less the unique LM characteristic, gradual properties changes, have future potential.

8 References

[1] Anonym Somos 201 Helps Reebok Stay On Course, DSM application note, June, 2000
[2] Clausen et al., laser sintering thermoplastic powder US 6.110.411 Patent
[3] Childs T:H: Tontowi; 2001; Selective laser sintering of a crystalline and a glass-filled crystalline polymer: experiments and simulations; Proceedings of the Institution of Mechanical Engineering, Journal of Engineering Manufacture; Vol. 215 B11 ISSN 0954-4054; pp 1481-1495
[4] DIN EN ISO 868, Kunststoffe und Gummi; Bestimmung der Eindruckhärte mit einem durometer (Shore-Härte)
[5] Levy G.N.; 1997; Systematische Werkstoffentwicklung erweitert den Nutzen beim Einsatz von Selektive LASERsintern SLS; Proceedings WZMO Lausanne October 1997
[6] Levy G.N, Schindel, R.,.Kruth J.P, 2003, Rapid Manufacturing and Rapid Tooling with Layer Manufacturing (LM) Technologies, State of the Art and Future Perspectives, CIRP Annals 2003 Volume 52/2/2003, pp 589-60
[7] Boehler P., Levy G.N., Martinoni R., Schindel R., Schleiss P., 2005, Sintaflex a new Elastomer powder material for the SLS Process, Rapid Prototyping & Manufacturing, May 9-12, 205 Dearborn MI
[8] Rogers B., Stephens S., Gitter A., Bosker G., Cped , Crawford R., Double-Wall, Transtibial Prosthetic Socket Fabricated Using Selective Laser Sintering: A Case Study, Journal of Prosthetics and Orthotics , 2000 Vol. 12, Num 3, pp 97-100
[9] Faustini M., Lokhande M., Crawford R. Rogers W. Gitter A., Bosker G., Finite Element Structural Analysis of Prosthesis Sockets For Below-The-Knee Amputees Manufactured Using SLS, Solid Freeform Fabrication Proceedings, 2001, pp 381-391
[10] http://www.3trpd.co.uk/index.htm We run the largest sintering capability in the UK
[11] http://www.hildebrand-gmbh.com/ eng/index.htm, Durometer
[12] PED CAD Germany http://www.pedcad.de/beginn.php3
[13] http://www.3dsystems.com/