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Mechanical Engineering and Machine-Building Technologies

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MECHANICAL ENGINEERING AND MACHINE-BUILDING TECHNOLOGIES

Content

WED-ONLINE-SSS-MEMBT-01

EXPERIMENTAL STUDY AND ASSESSMENT OF THE CAUSES FOR VIBRATIONS IN MACHINING TECHNOLOGY SYSTEMS DURING FACE MILLING OPERATION

Danimir Dimov – Student
Department Mechanical and Manufacturing Engineering,
University of Ruse "Angel Kanchev", Ruse, Bulgaria
Phone.: 082 888 653
E-mail: ddimitrov@uni-rusel.bg
dhdimov88@gmail.com

Abstract: *In order to reduce and limit the vibrations caused by physical forces in the processes of machining, the stability of the technology system can be increased by placing additional supports and clamps to better fixate the workpiece. The positions of such fixations must correspond to the system`s own natural frequencies of vibration and oscillation shapes. The application of external forces with frequencies, approaching or equal to those of the system, causes an unwanted phenomenon called resonance. Some workpieces, such as thin-walled beams, are especially susceptible to these vibrations. To know which frequencies can cause mechanical disturbances in the process of machining, we need information about the spectrum of frequencies which the specific tool and operation parameters can induce upon the technology system. The purpose of this study is to determine the spectral characteristics for specific cases of machining through experimentation and analysis.*

Keywords: *Technology, Machining, Metal cutting Milling, Vibrations, Resonance*

INTRODUCTION

A distinct aspect of modern mechanical manufacturing, large or small scale, is the tendency of apllying automation (Penchev M.S., I. Peeva. (1995), (Kostadinov Ch., I. Peeva.) (2017,2019,2020), digital technology and CNC machines. The high economic cost of equipment, combined with the high productivity demand, require a certain efficacy of all processes. It is widely accepted that physical stability is one of the main requirements to a manufacturing process' efficacy. Each system component – machine, device, tool, workpiece, with its own mechanical properties, has an effect on the total stability. (Angelov, Yu. A. 1999,2010), (Bozduganova, V.,M. Todorov. (1993), (Enchev PT, YA Angelov. (2004). In the ever developing machining technologies, a main problem concerning efficacy are vibrations of the technology system, caused by the forces of machining. Every technology system has its own vibration frequencies, which depend on the constructional features and mechanical properties of the materials. (Stoyanov Sv., St. Stoyanov. (2011), Stoyanov, S. (2014,2017). External forces, applied with equal to the natural frequencies of the system, can cause resonance. Resonance is related to the amplitude of oscillation of the workpiece and affects the machining process negatively, leading to inconsistent surfaces and dimensions. For that reason, the natural vibration frequencies and amplitudes of the workpiece (and other elements of the system) must be determined, especially in cases of insufficient mechanical stability. Scientific achievements and discoveries, combining fundamental mechanics with computer software-aided modeling and simulation, make the quick application of engineering solutions possible. (Bozduganova, V.,M. Todorov. (1993), (Draganov I. (2016), Draganov I., R. Milkov, A. Pukhlev. (2018), Draganov I., N. Ferdinandov, D. Gospodinov, R. Radev, S. Mileva. (2019), Velchev, D. (2003). Having obtained information about the vibration characteristics of the system, the following steps can be undertaken in order to reduce vibrations: **1)** Dissipation with the help of vibration-absorbing devices, **2)** Avoiding the application of external disturbances with frequencies equal to the natural ones, through altering the machining parameters related to the frequency of the tool striking the workpiece surface. That means how many times the edges of the tool strike the worpiece for a given amount of time. **3)** Increasing the stability of the technology system. To increase the stability of the workpiece itself, additional fixations can be applied at the appropriate areas of deformation (maximum amplitude) in the process of oscillation. (Dimitrov D., I. Georgiev.(2015), (Dimitrov D, N. Nikolov (2019). The latter two solutions aim to reduce the possibility of causing resonance and stabilize the system in its critical areas. That demands information about the frequency characteristics of any external disturbances and of the system itself. Because the frequency spectrum of any technology system is strongly individual and specific, it must be determined for each such system. Determination of the applied forces with a given frequency in advance is only possible through calculations related to the number of cutting edges of the tool and the revolutions per minute. Any other disturbances, which have an effect because of their frequencies, are related to other parameters of the machining process, such as the formation and break-off of chips, and are not analyzed at this point.

EXPOSITION

Description of the experiment and expected results

Apllying the forementioned solutions requires an understanding of the amplitude-frequency characteristics of the specific machining process. As was already explained, that can only be achieved through numerical analysis of the frequency of the incisions that the tool's cutting edges perform into the workpiece. Another step in determining these characteristics is analysis through means of experimentation. The obtained data must be reliable and repeatable, so that it may be significant.

The experiment aims to answer the following questions: **1)** Is there any sort of repeatability in the frequency spectrum of the technology system for every set of equal conditions, but different instances, or is it variable and undetermined, and **2)** What impact do the number of the tool's cutting teeth and machining parameters have on the frequency spectrum and could they be altered to reduce vibrations.

The experimental set-up (Fig. 1) consists of a CNC machine, a test workpiece, an accelerometer and a PC. The solid steel test workpiece is fixed to the machine's work table and the accelerometer is attached to it. The PC with the appropriate software allows us to vusialize the measurements and data regarding the vibrations, detected with the accelerometer. The test workpiece is fixed with two clamps in a holding device, which is attached to the work table. The used tools are two different mill heads, which have respectively 7 and 8 cutting edges and external diameters of respectively 80 and 100 milimeters. Seperate sets of tests were conducted with each tool.

The expected results are that the frequency spectrum of vibration of the technology system is repeatable and that it does not vary unexplainably, and that vibrations with certain frequencies are related to the rpm and amount of cutting teeth of the tool.

Pos. 1 – Work table

Pos. 2 – Accelerometer, attached to test piece 3 and connected to PC 6

Pos. 3 – Solid steel test workpiece, fixed to the work table 1

Pos. 4 – CNC machine – 5-axis mill

Pos. 5 – Machining tool – mill head

Pos. 6 – PC with appropriate software loaded – Soundcard Scope (Soundcard Oscilloscope)

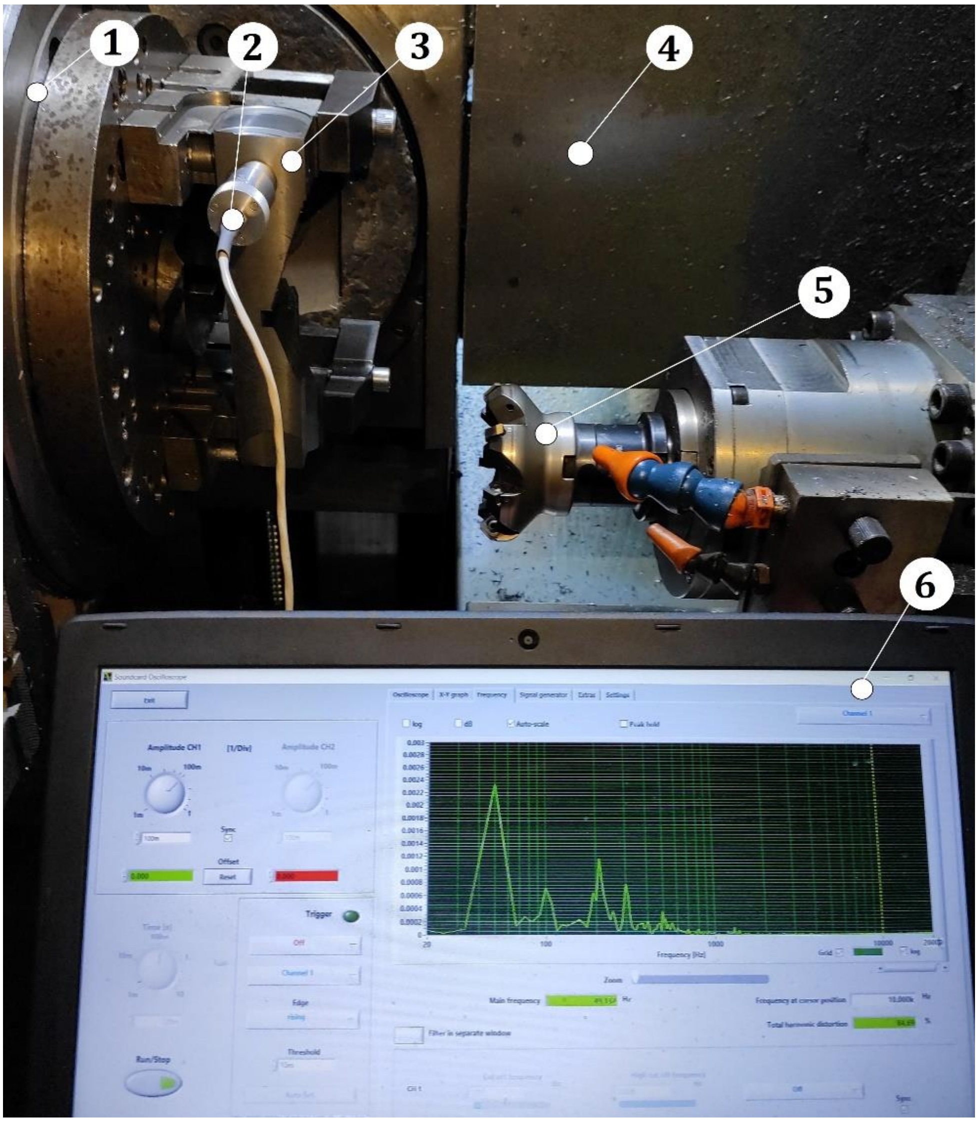

Fig. 1 – Experimental setup

Experimental conditions

The tests have been conducted in a certain order. The required information is about the frequencies of vibration in the process of cutting (machining), and also in resting conditions, the so called 'dry run'. First, measurments were made at dry run at 250 rpm, than 500, 1000 and 2000 rpm. That means that the series of tests was conducted in the absence of contact between the tool and the workpiece – no cutting is being executed, so no forces are transferred from the tool to the workpiece. These frequencies of rotation fall into both rpm bands which the machine's gearbox has.

The next set of test was conducted in the process of machining – the tool is in contact with the workpiece and actual processes of cutting are applied. So at each of those four rotary frequencies (250, 500, 100, 2000 rpm) 5 tests (measurments) were performed at dry run and 5 more in cutting conditions. This series of tests was conducted using a 7-edge tool. Apart from them, the same sets of 5 measurments were taken when using an 8-edge tool at 500 rpm. That allows us to compare the vibration frequencies induced by each of those tools.

In order to grant repeatability and reliability of the results, all other conditions remained constant or (some) were changed according to certain principles. The depth of cut in all instances was a=0,4 mm. The work path of the tool was y=60 mm in length. The feed was related to the rpm (frequency of rotation-s) in each case – at s=250 rpm, f=175 mm/min. At s=500 rpm, f=350 mm/min. At s=1000 rpm, f=700 mm/min. At s=2000 rpm, s=1400 mm/min. These values of feed rates were calculated from the equation:

$$f = f_z * z * s\ , \quad [\text{mm/min}]$$

where f – minute feed, f_z – feed per tooth, z – number of teeth, s – rpm.

Feed per tooth was f_z=0,1 mm for each case.

With the parameters feed per tooth and depth of cut kept constant for each instance, equal conditions are insured. The only parameter used as a variable is the frequency of rotation.

Results and interpretation

As a result of the experiment and with the help of the mentioned software, the following diagrams of the frequency spectra were created.

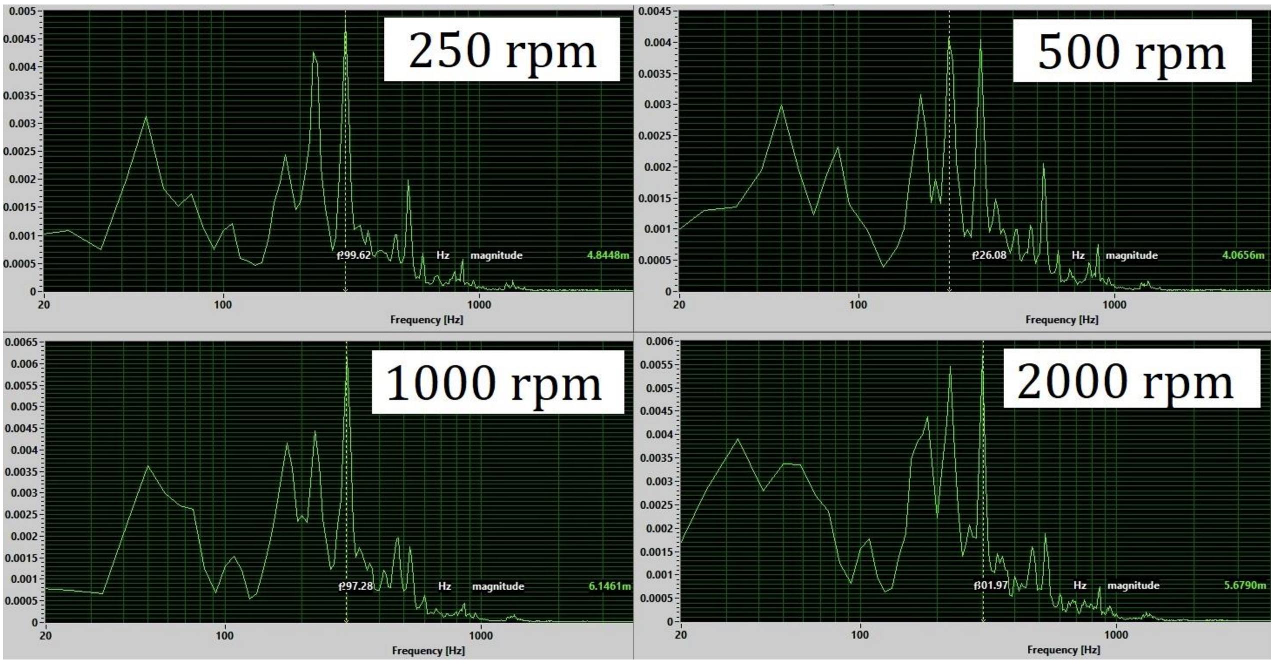

Fig. 2 – Comparison of frequency spectra at dry run

Fig. 2 shows the frequency spectrum of each of the 4 chosen rpm cases at dry run - 250, 500, 1000 and 2000 rpm. As expected, these 4 charts do not have significant differences. The maximum amplitudes (vertical axis) are related to the same frequencies (horizontal axis) in all cases. The peaks can be assumed equal in number aswell.

It can be concluded that the frequency spectrum in resting conditions does not change unexpectedly. It cannot be predetermined accurately, but the revolutions per minute by themselves do not have a significant effect upon it. In equal conditions the natural frequency range remains constant enough for the purposes of machining.

On Fig.3 we see a comparison between the frequencies of oscillation in working conditions – actual forces of machining (cutting) apply. Again, in the same rpm range, the frequency spectra are

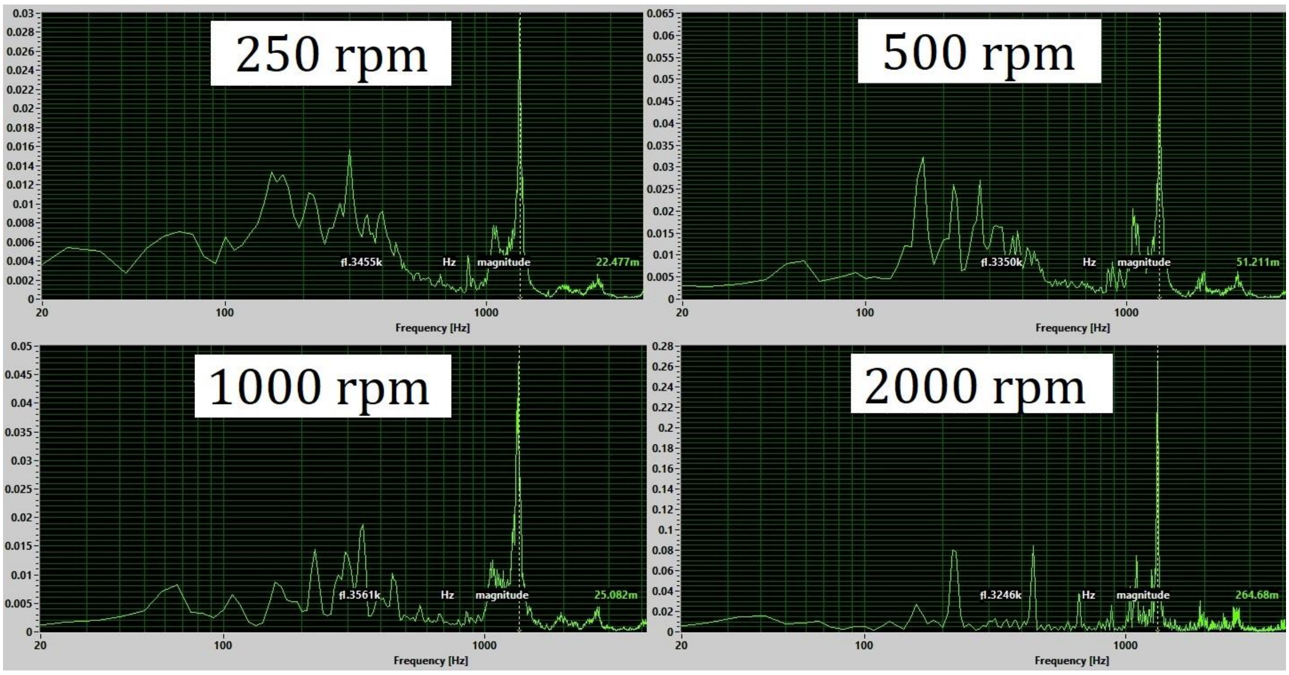

Fig. 3 – Comparison of frequency spectra in working conditions

very similar. The maximum amplitude peak is around 1040 Hz in all cases. Above that frequency a subsidence of the vibrations follows. The other peaks are also similar.

Determination of critical frequencies

Ctitical frequencies are those, which pose a risk of developing resonance when paired with their equal counterparts from the natural frequency spectrum of the system. In other words, when an external frequency becomes equal to one of the natural frequencies, the amplitudes of both combine and cause a strong vibration with a high resulting amplitude. When the workpiece (or other system components) vibrates that strongly, the process of machining is highly impaired.

When working with a given multi-toothed tool, as a result of the tool’s rotation, the teeth strike the workpiece with a specific frequency. That frequency can be calculated as:

$$f = \frac{s*z}{60}, \quad [Hz] \qquad (2)$$

where f – frequency,

s – revolutions per minute,

z – number of teeth of the tool

That is how we can determine the frequency of strikes of the teeth on the workpiece surface for every chosen number of teeth and rpm.

Knowing that frequency, through consultation with the technology system’s natural spectrum, resonance could be avoided. That can most easily be done through altering the externally applied critical frequency, through changes in the two studied machining parameters – rpm and number of teeth.

On Fig.4 One can see a rise in the amplitude at frequency around 70 Hz when working with an 8-tooth tool and 500 rpm. Through the equation (2) we can work out that at that rpm and number of teeth, the frequency of striking is $f = \frac{500*8}{60} = 66{,}7$ Hz. The chart shows this very frequency has a local maximum amplitude, although in the low range of up to 0,03.

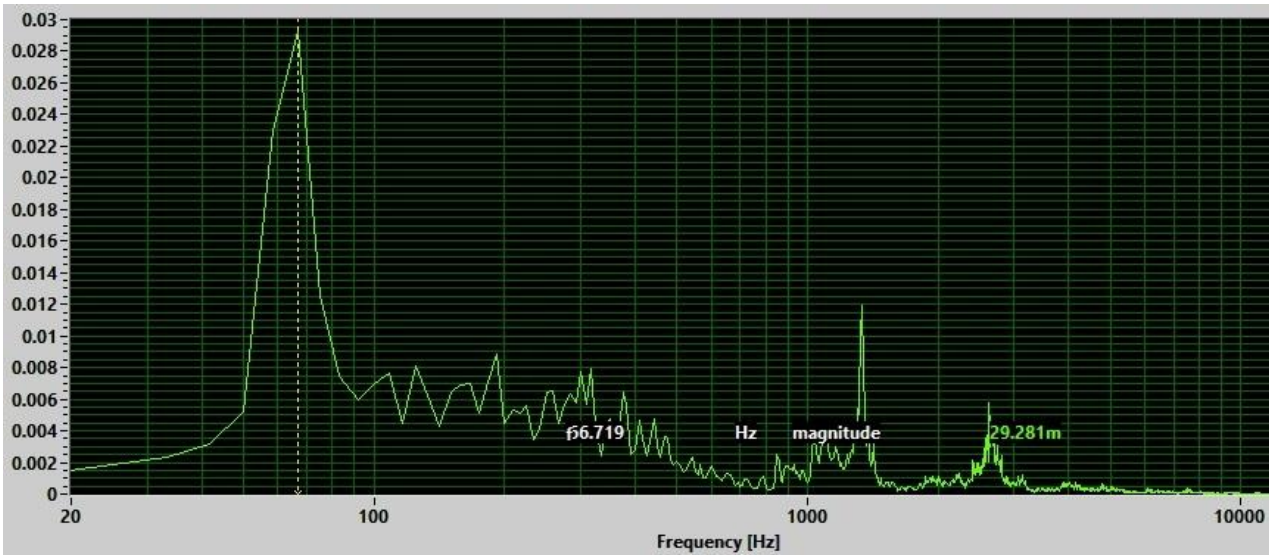

Fig. 4 – Frequency spectrum of vibration when using an 8-tooth tool, 500 rpm

CONCLUSION

The carried out experimental study confirms the direct relationship between the generated frequencies and applied external disturbances as a function of the periodic striking (incisions) of the tool's cutting edges, with its momentary rpm, onto the workpiece.

Changing the frequency of rotation (rpm) of the mill-head tool does not affect the resulting frequency characteristic significantly, but only the amplitudes of certain frequencies.

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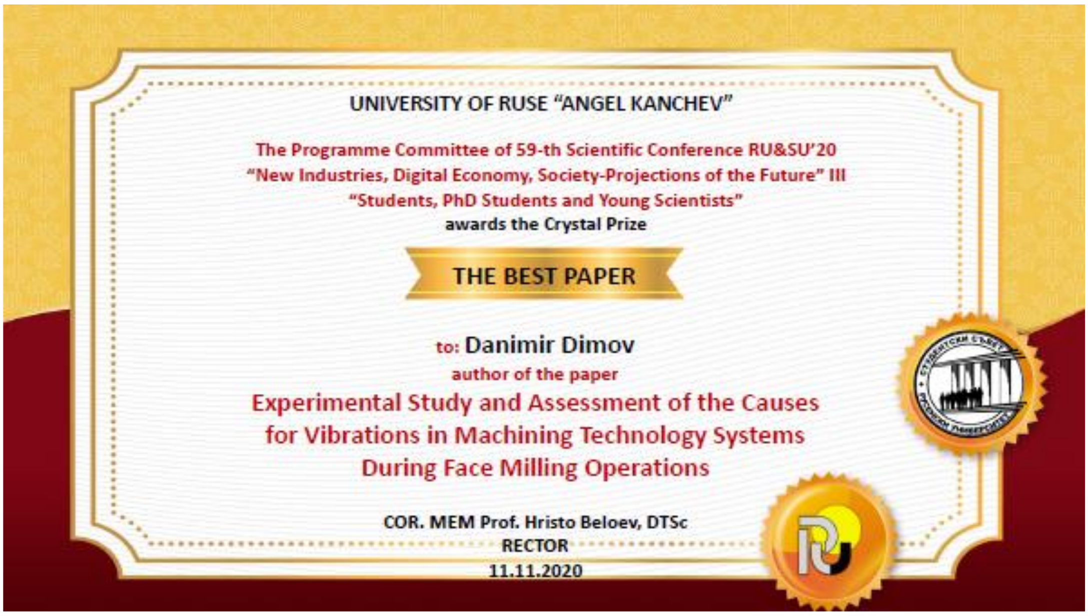

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INVESTIGATION OF THE SHRINKAGE POROSITY FORMATION OF AL-SI ALLOY

Daniela Nenova – Student,
Trifon Gospodinov – Student,
Iskren Penev – Student,
Aleksandar Kamenov – Student,
Dobromir Kamenow – Student
Department Mechanical and Manufacturing Engineering,
University of Ruse "Angel Kanchev"
Tel.: +359 82 888 778(311)
E-mail: rminev@uni-ruse.bg

Abstract: *A study of the susceptability to shrinkage and porosity of Al-Si alloy with a sub-eutectic composition has been presented in the paper. The experiments were performed on casting test pieces produced in metal molds and sand molds with different water content (fast cooling and slow cooling respectively). In this way, the different influence of the cooling rate on the volume of the formed external shrinkage has been shown. The results revealed that, depending on the type of mold, the cooling rate affects the shrinkage volume differently. This phenomenon is explained by the difference in the shrinkage of the alloy in liquid and solid state at high and low cooling rates.*

The results of shrinkage simulation experiments with specialized software, are also presented and analyzed in the work.

Keywords: *Shrincage porosity in castings, Al-Si alloy, simulation of casting shrinkage*

1. Въведение

Една от особеностите на леярските технологии е свиването на метала. Известно е, че с изменение на температурата на метала се изменя неговия обем и линейните му размери. След заливане температурата на метала започва да намалява, което води до свиване и намаляване на обема на отливката. Освен това при затвърдяване обема допълнително намалява с до 13%. Последното води до образуване на всмукнатини и пористост. В такъв смисъл свиването се явява една от най-важните характеристики за сплавта, определяща размерите на отливката, нейната плътност, възможността за получаване на напрежения, пукнатини и деформации [1-3].

В следствие на свиването, в зависимост от вида на сплавта, формата и начина на запълване се наблюдават кухини, нарини всмукнатини. Когато са малки по размер те се наричат пори. Тези дефекти се получават в периода на кристализация, като резултат от фазовото превръщане и особеностите на охлаждане на отливката. Теоритически те са безвъздушни, а практически са запълненни с газове от отливката, отделили се в резултат на възникналия вакуум. Повърхността им е груба, тъмна, с неправилна форма, като често пъти се наблюдават отелни дендрити, за разлика от газовите шупли, чиято повърхност е гладка и блестяща [1,4]. Всмукнатините могат да бъдат и външни, изразяващи се в локално "хлътване" на повърхността на отливката.

В зависимост от мястото в отливката и от характера на кристализация всмукнатините могат да бъдат концентрирани (външни или вътрешни), или разсеяни - т.н. пористост. Порите обикновено не се забелязват с просто око, но когато пористостта е образувана в топлинен център при групиране на голям брой пори, то тази зона става видима.

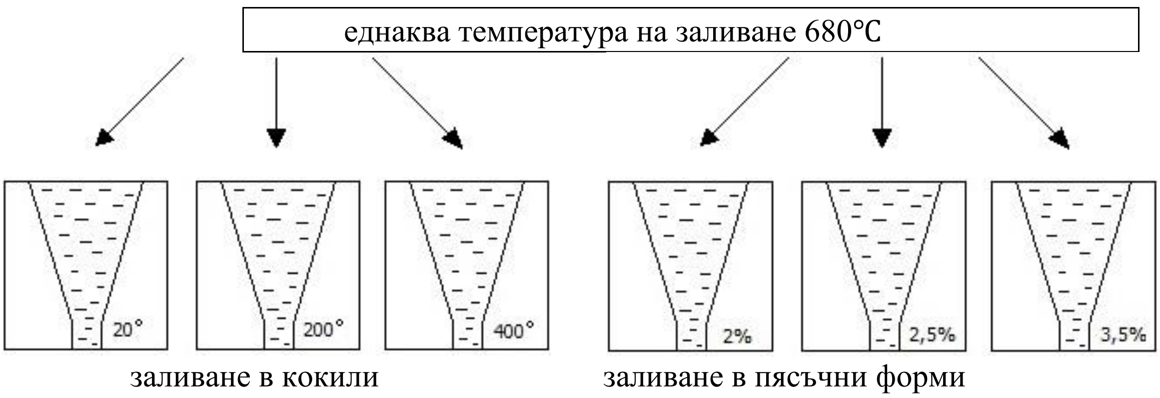
Всмукнатината и пористостта са нежелан ефект при получаването на отливки [5-9], за това е необходимо да се използват различни методи за отстраняването или минимизирането им по време на технологичния процес. Тези методи са:

- Метод за едновременно затвърдяване (за метали с малка склонност към всмукнатини, легирани - с широк интервал на затвърдяване и при по-тънкостенни отливки). Този метод цели да се образуват пори, които да бъдат изведени към наливната система;
- Метод на насочено затвърдяване (при сплави имащи склонност към образуване на всмукнатини - чисти, евтектични или близкоевтектични сплави, с малък интервал на затвърдяване). При този метод кристализацията протича постепенно от най-отдалечените места на формата към подхранващо устройство наречено мъртва глава, което изстива последно и се отстранява;
- Подаване на течен метал през няколко питателя за едновременно запълване на всички части на отливката и осигуряване приток на метал в евентуално възникнали всмукнатини;
- Ако има тънки и дебели части, подаването да се извършва през тънките за да се стимулира едновременното затвърдяване.

Скоростта на охлаждане е един от параметрите, влияещи на свиването, респективно на образуването на всмукнатини и пористост. При леене в пясъчни форми скоростта на охлаждане зависи от влажността на формовъчната смес, а при металните - от температурата на формата. В настоящия екстеримент се изследва влиянието на температурата на формата (метална форма) и влажността на формовъчната смес (пясъчна форма) при еднаква температура на заливане върху склонността на алуминиева сплав (AlSi) към образуване на всмукнатини.

2. Методика на изследването

За да се установи влиянието на температурата на формата за настоящия експеримент се използват шест пробни тела с еднаква форма, състояща се от конусна и цилиндрична част. Разстопения метал се излива в три метални форми (кокили), предварително нагряти, всяка до различна температура, и в три пясъчни форми, като всяка форма е с различно влагосъдържание на формовъчната смес (Фиг.1).



Фиг. 1 Схема на провежданите експерименти. Скоростта на топлоотвеждане (скоростта на охлаждане) се увеличава в представените от ляво на дясно проби.

След като пробните тела се охладят до стайна температура, те се изваждат от формите и с помощта на ръчна ножовка се разделя конусивидната от цилиндричната им част (Фиг.2). От конусовидната част се прави изследване на обема на всмукнатината, а псредством цилиндричната - на пористостта. Основната цел на експеримента е насочена към изследването на обема на всмукнатините и плътността на пробите.

В зависимост от скоростта на охлаждане (температура на формата и влажността на формовъчната смес) обема на всмукнатините при еднаква температура на заливане се очаква на бъде различна. За целта той се определя, като всмукнатината се запълва с течност подавана от измерителен цилиндър (със скала и кранче), пълен с изопропанол, който се накапва във всмукнатината без преливане. Отчита се разликата на нивото на течността по скалата. С електронна везна (с точност 0,005 g) и универсален шублер се измерват масите и размерите на телата, след което се изчисляват обемите и плътностите им.

Фиг. 2 Форма на пробните тела - цилиндрична и конусовидна част.

В таблици се нанасят предварителните и изчислените данни за всяко от пробните тела съответстващи на метода на леене и се правят съответните анализи.

Със специален софтуер (***FLOW-3D CAST v5.1 и DS SOLIDWORKS***) се провежда симулация на експеримента за процеса на леене в метални форми (кокили). Етапите от създаване на модела и параметрите на симулирането с *FLOW-3D CAST v5.1* са:

- създаване на CAD модел на пробните тела: (i) 2D скица, (ii) "револвиране" на скицата, (iii) създаване на 3D модел;
- създаване на мрежа от крайни елементи.
- задаване на основните параметри: време на заливане, налягане, температура на течния метал, химичен състав, температура на формата, диаметър на наливане и др.
- стартиране на симулацията.
- разчитане и сравняване на резултатите.

3. Резултати и анализи

В Таблица 1 и Таблица 2 са представени резултатите от измерванията след проведените експерименти.

Става ясно, че данните, снети от първоначалните измервания на диаметрите и височините имат голяма дисперсност. Това се дължи на неравномерното хлътване на метала в горната част на отливката, и на механичното разделяне на конусната и цилиндричната части. Това се дължи на неравномерното хлътване на метала в горната част на отливката, и на механичното разделяне на конусната и цилиндричната части. Тези разлики не оказват съществено влияние при изследването на всмукнатини, но при пористостта се наблюдават големи скокове в получените резултати. Очаква се при по-голяма скорост на охлаждане порите да са с по-голяма концентрация и на по-голяма дълбочина в отливката, но от получените резултати се вижда, че плътностите на цилиндричните проби, отлети в метални форми с различна температура са с незначителна разлика в плътността.

Таблица 1

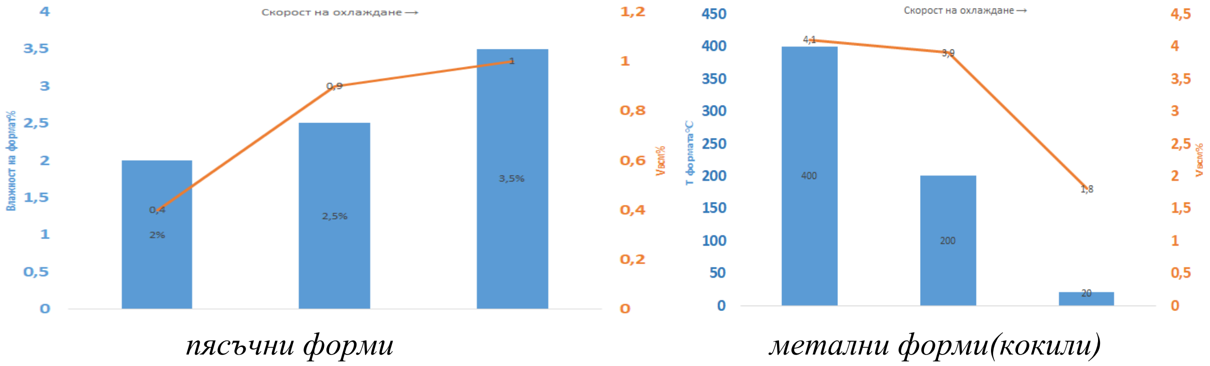
пробно тяло	влаж - ност,%	диаметър D, d [mm]		височина H, h [mm]	маса m [g]	$V_{пр. тяло}$ [cm^3]	$V_{всм}$ [cm^3]	$V_{всм}$ %	плътност ρ[g/cm^3]	% пористост
конус	2	D_2= 24,62	D_1= 68,47	h= 105,81	-	193,06	0,7	0	-	-
	2,5	D_2=24,58	D_1= 69,65	h=106,38	-	199,311	1,8	1	-	-
	3,5	D_2= 24,49	D_1= 70,66	h= 107,2	-	205,21	2	1	-	-
цилиндър	2	d = 15,14	-	H= 18,31	m= 9,23	3,296	-	-	2,8	0
	2,5	d = 17,25	-	H= 18,40	m= 9.43	4,3	-	-	2,19	22
	3,5	d = 15,30	-	H= 18,44	m= 9,44	3,9	-	-	2,78	0,7

Таблица 2

пробно тяло	$T_{кокила}$, oC	диаметър D, d [mm]		височина H, h [mm]	маса m [g]	$V_{пр. тяло}$ [cm^3]	$V_{всм}$ [cm^3]	$V_{всм}$ %	плътност ρ[g/cm^3]	% пористост
конус	20^o	D_2= 22,41	D_1= 67,79	h= 101,93	-	140,847	2,6	2	-	-
	200^o	D_2=22,59	D_1= 69,26	h=103,65	-	186,471	7,3	4	-	-
	400^o	D_2= 23,8	D_1= 69	h= 102,08	-	186,26	7,6	4	-	-
цилиндър	20^o	d = 19,93	-	H= 19,74	m= 17,03	6,158	-	-	2,766	1,2
	200^o	d = 19,81	-	H= 19,76	m= 16,78	6,09	-	-	2,755	1,6
	400^o	d = 19,97	-	H= 19,78	m= 17,18	6,195	-	-	2,773	1

Т.е разултатите по отношение на плътността на пробите не показват отчетлива тенденция на измемение при увеличване на скоростта на охлаждане. Вероятно това се дължи на недостатъчната точност на определяне на обема. За това се препоръчва изследването за пористост да се извърши с пикнометър.

Изследването на обема на всмукнатината показва, че при леене в пясъчни форми (Фиг. 3,а), увеличаването на влажността на формата (по-висока скорост на охлаждане) води до увеличаване обема на всмукнатината.

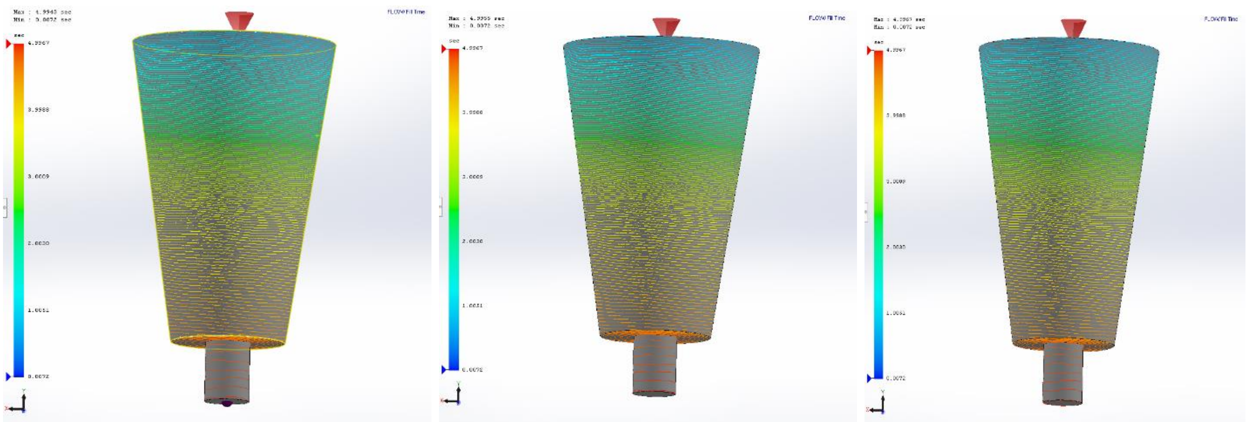


(а) (б)

Фиг. 3 Измемение на обема на всмукнатината при увеличаване скоростта на охлаждане при леене в (а) пясъчни и (б) метални форми.

При експериментите проведени с метални форми (Фиг. 3,б) се установява, че с увеличаване на скоростта на охлаждане (в случая намаляване на температурата на формата) обемът на всмукнатината намалява. (Тази тенденция е обратна на наблюдаващата се при пясъчните, където обемът на всмукнатината се увеличава с увеличаване на скоростта на охлаждане в резултат на увеличаване влагосъдържанието на формовъчната смес. Този феномен в литературата се обяснява с различната скорост на изменение на топлинното разширение (свиване) в течно и твъдо състояние. При ниски скорости на охлаждане (керамични и пясъчни форми) свиването в течно състояние расте по-бързо (с увеличаване скоростта на охлаждане) и определя нарастващия обем на всмукнатината, докато при по-високите скорости на охлаждане (метални форми) свиването в твърдо състояние расте по-бързо и способства за намяляване на нейния обем [1,4,5].

След провеждане на компютърните симулации се наблюдават закономерни и потвърждаващи се от експериментите резултати (Фиг. 4).

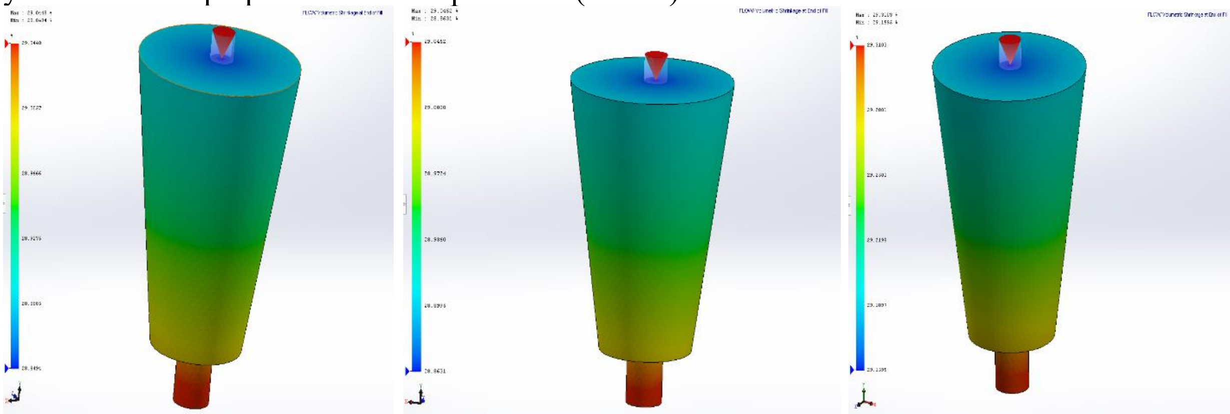


(а) (б) (в)

Фиг. 4 Резултати от симулиране времето на запълване на формите при различна температура на формата: (а) - 20°С ; (б) - 200 °С; (в) - 400°С.

Фиг. 5 Газов мехур, получаващ се при заливане на форма с температура 20 ºC.

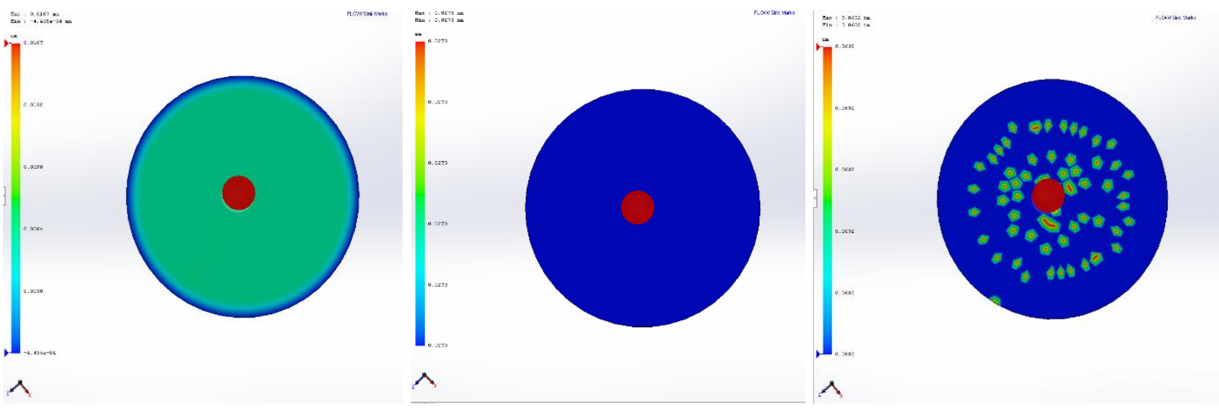
При температура на формата 20°C, времето запълване е най-малко (Фиг. 4). Това се дължи на процеса на кристализация, който започва по-рано. Образуват се дендритни кристали, което води и до намаляване на плътността. Поради пресичането на потоците при заливане и бързото охлаждане, в долната цилиндрична част се образува газов мехур, който се установява и при реалните експерименти (Фиг. 5).



(а) (б) (в)

Фиг. 6 Изменение на плътността на отливката в зависимост от температурата на формата: (а) - 20ºC ; (б) - 200 ºC; (в) - 400ºC.

Изследванията на плътността на отливката, показвт че тя е най-ниска при температура на формата 20°C (дендритни кристали). При 400°C меала е по-дълго време в течно състояние, което води до по-висока плътност. Обема расте съобразно с времето.



(а) (б) (в)

Фиг. 7 Разпределение на свиването и всмукнатината в зависимост от температурата на формата: (а) - 20ºC ; (б) - 200 ºC; (в) - 400ºC.

Установява се (Фиг. 7), че при най-студената форма всмукнатината е разпределена по цялата площ равномерно, поради високата скорост на охлаждане. Само по външната периферия кристализацията е с по-висока скорост. При 200°C, изстиването на кокилата и течния метал става сравнително едновременно(хомогенно), докато при 400°C, поради високата температура на кокилата има наличие на дендритни зони на застиване, които създават условия за и за местни всмукнатини.

Изводи:

1. Обема на всмукнатината при различната скорост на охлаждане не превишава 1% при леене в пясъчна форма и 4,1% в метална;
2. Установено е същественото влияние на температурата на формата и нейната влажност върху скоростта на топлоотвеждане и склонността към образуване на всмукнатини и пористост.
3. Потвърдено е, че при по-бавно топлоотвеждане (пясъчни форми) увеличаването на скоростта на охлаждане води до увеличаване на всмукнатината, докато при по-интензивно топлоотвеждане (метални форми) ефектът от увеличаване скоростта на охлаждане е противоположен.
4. Симулацията на експеримента показва аналогични резултати.

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ARE ELECTRIC VEHICLES GOING TO TAKE OVER?

Vanyo Georgiev – Student
Department of Transport,
University of Ruse "Angel Kanchev"
Tel.: +359 82 888 230
E-mail: vanyogeorgiev00@gmail.com

Abstract: *Electric cars make up only a tiny fraction of the automobiles sold worldwide. However, this number is increasing steadily. In the future electric cars might be the only way of transport, although some people think electric transport can preserve vehicles with internal combustion engines. Also, some experts say we might even see a "revival" of such engines. This paper examines all the specifications of electric automobiles, according to different factors such as as price, performance, etc. Some advantages and disadvanatges of electric cars are also compared. An attempt is made to answer the questions as to when and how they will take over the sales and how this is going to affect cars with internal combustion engines.*

Keywords: *electic vehicles, internal combustion engines, comparison, future developments*

INTODUCTION

An electric vehicle (EV) is a vehicle that uses one or more electric motors or traction motors for propulsion (Wikipedia, 2020). An electric car may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel to electricity, for example an engine in hybrid cars. EVs include, but are not limited to road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft and their importance and usage has been increasing in the recent years.

This paper will focus on battery electric cars and hybrids in terms of several important features and factors such as sales and performance in order to assess the possible impact such vehicles might have on the future of internal combustion transport. Also, I will consider some specific examples about currently used EVs.

EXPOSITION

1. The importance of electric vehicles is growing globally. There are several factors that can be used to assess the future impact such automobiles might have on the utilization of currently used fuels and technologies such as the internal combustion engine and conventional fuel types. The factors I take into consideration are: sales figures and sales trends for EVs; prices; range; performance; comfort and running costs. I consider each of them separately in order to formulate and evaluate future predictions about the application of the predominant present-day technology.

1.1. Sales

Electric cars make up only a tiny fraction of the automobiles sold worldwide. However, this number is increasing steadily. In the future electric cars might be the only way of transport. In the past few years sales have been increasing and are expect to continue to grow in the future. For example, as of early December 2015, the Nissan Leaf with 200 000 units sold worldwide, was the world's top-selling highway-capable all-electric car of all time, followed by the Tesla Model S with global deliveries of about 100 000 units. In 2016 the sales of EVs was only 2% of all cars sold around the globe. Leaf global sales achieved the 300 000 unit milestone in January 2018.

The calculated rise in sales in 2019 as compared to 2018 was 60%, although this growth was unnoticeable. The lift off point of sales is predicted to begin in 2022. If sales continue to grow in such rates, by 2030 EVs would account for 22% of new vehicle sales and by 2040 they will account for 35%.

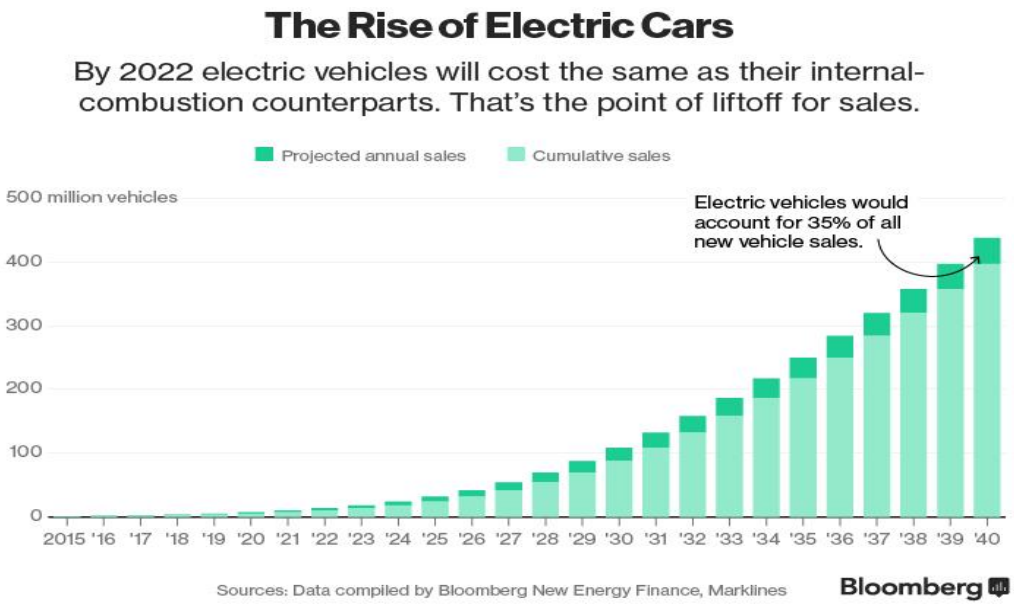


Fig.1 The Rise of Electric Cars

1.2. Prices

Generally, electric vehicles (EV's) are more expensive to buy in comparison to vehicles with internal combustion engines (I.C.E). Although this is likely going to change, the present day technology available will not allow this to happen soon. For a simple example (Table 1), the Hyundai Kona is compared in terms of price as a normal car with an ICE and as fully electric battery EV (BEV). (data collected from data collected from www.edmunds.com) (MSRP- List price)

Table.1

	ICE	Electric
MSRP	$ 23 425	$ 38 365
Tax Incentives	None	$ -8 000
Total	$ 23 425	$ 30 365

The main reasons for the higher prices are the batteries. The Li-Ion battery technology has started to look outdated. These batteries cost on average a third of the whole price of an EV. The primary causes of this are the high prices of production of such batteries and the difficulty they impose on their transportation because of their high weight.

Table 2 lists some of the most popular electric cars and compares their list prices. The tax incentive amount is also taken into consideration.

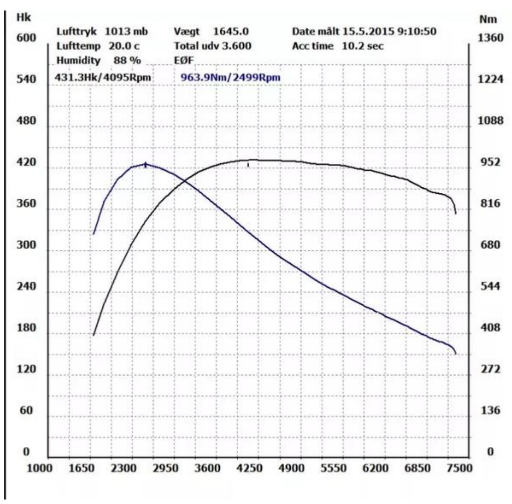
Table.2 - Average prices and tax incentives calculated by using data from www.electrek.co

Car	Average MSRP	Average tax incentive
Chevrolet Bolt	$ 41 079	$ -8 500
Audi e-tron	$ 77 841	$ -7 049
Hyundai Ioniq	$ 39 180	$ -2 000
Chrysler Pacifica EV	$ 50 515	$ -5 000

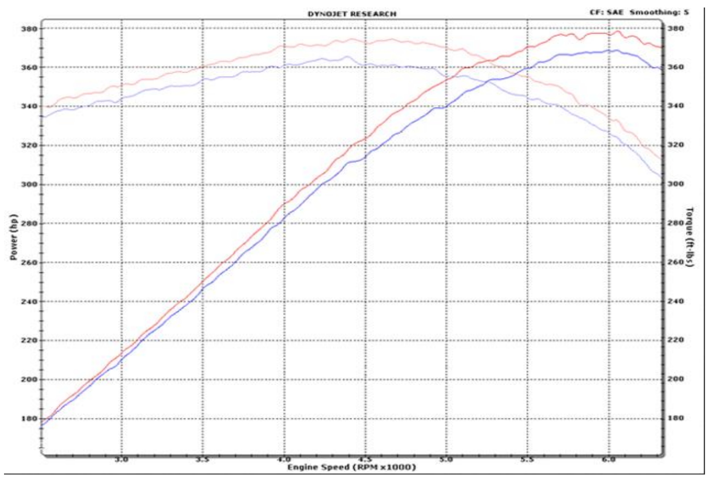
Jaguar I-Pace	$ 81 752	$ -7 380
Kia Niro	$ 42 893	$ -3 000
Nissan Leaf	$ 42 693	$ -6 000
Toyota Prius Hybrid	$ 32 118	$ -3 500
Mitsubishi Outlander PHEV	$ 41 692	$ -4 160
Volkswagen e-Golf	$ 39 999	$ -3 870
Tesla Model S	$ 91 155	$ -7 425
Tesla Model 3	$ 50 990	$ -3 900
Tesla Model Y	$ 55 000	$ -4 150
BMW i3	$ 46 050	$ -3 490
Porsche Taycan Turbo S	$ 210 800	$ -14 820

1.3. Performance

This is one of the most interesting characteristics of EV's. On the whole, electric cars have very high acceleration because of the high torque figure from the start line. However their top speed is not very impressive. The reasons for this are several. Firstly, electric motors apply torque by using electricity stored in batteries. Having all the energy stored inside the car lets them have great amount of torque very quickly, but in exchange, the motors and circuits have considerable power limits. Figure 2 (Vaught, 2017) shows a graph of power and torque parameters for an electric car. It is noticeable how the engine makes makes a significant amount of torque quickly, and then loses it as it hits a power cap. Another limitation is that EVs have only 1 gear.



(fig.2)



(fig.3)

The fastest accelerating electric vehicle at present is Tesla Model S Performance which accelerates from 0-100 kilometres per hour in 2.5 seconds. However, when it hits the power cap mentioned above it is able to reach a top speed of only 261 km/h and this also makes it the EV with the highest top speed. It is powered by a 100 kWh battery and has a power output of 580 kW (778 hp) and 1140 NM of torque.

In 2022 it is expected that Tesla will release the quickest vehicle ever build, called the Tesla Roadster, with an sublime acceleration of 2.1 seconds from 0-100 km/h. It is also predicted to have a top speed of 410 km/h. It estimated to be powered by a 200 kWh battery and it is said that it will have a power output of 1000 kW (1341 hp) and 1200 NM of torque. (https://ev-database.org/compare/quickest-acceleration-electric-vehicle)

Petrol motors, in comparison, apply torque by exploding a mixture of gasoline and air. Although fuel can be added as quickly as needed, the air has to be pulled in as the engine rotates. This means that a petrol engine cannot produce torque quickly, but makes more and more power as it spins faster. Figure 3 (Vaught, 2017) shows a graph of power and torque for a gasoline engine; it is worth noticing that the power just keeps climbing as the motor spins up.

If we compare individual vehicles according to their performance we can notice that the 2015 Porsche 918 Spyder is the fastest accelerating vehicle ever produced, with acceleration from 0-100 km/h of 2.1 seconds which, importantly, it is powered by both an ICE and 2 electric motors that combined make 893 hp. In comparison, the quickest ICE car is the Porsche 911 Turbo S, with an acceleration of 2.2 second, which is surprisingly quicker than the quickest EV. It can achieve such acceleration because its drivetrain is made out of a 640 hp, 3.7 litre twin-turbo flat-six cylinder engine, an eight speed dual-clutch transmission and a very intelligent AWD (all-wheel-drive) system. At the same time, the ICE vehicle with the highest top speed is the Koenigsegg Agera RS. It can reach a top speed of 447 km/h using its 5 litre twin-turbo V8 engine which produces 1341 hp.

1.4. Range and efficiency

In the past 10 years, range has been a very big issue for electric transport. Although today most electric cars can easily go at least 300 km with one charge, it is still very far from the figure for cars with I.C.E. For example my personal vehicle, which has 1.9 litre four cylinder diesel engine can achieve a range of around 1300 kilometres on highway only driving.

The risk of running out of electricity has given rise to the phrase 'range anxiety'. As with any new technology, our understanding of it has not yet developed, and the unknown element of electric cars has turned many drivers off of the idea of buying one. But this needn't be the case, especially in the year 2020, as electric cars are not only becoming more common on roads, they're also becoming much more realistic alternatives to traditional petrol or diesel cars. The best models will offer up to 500 kilometres of range per charge, which is not far off what you' expect from a tank of petrol.

In Table 3 a summary of a real world test that was conducted by ‘carwow’ is given (https://www.carwow.co.uk/)

Description of the experiment: The cars were charged to 100% battery and were left overnight to make the test realistic. In the morning all of them had over 95% charge. All cars were driven in a very similar way to make the test fair. All vehicles are set into their most energy efficient setting. The air conditioning was set to 20^{o} C. The driver’s phones were connected to the infotainment system of their cars. Ambient temperature was a minimum of 7^{o} C and a maximum of 10^{o} C. The cars were always driven with the speed limit on the road that they were driven on.

(Table.3)

Car	Claimed range	Real world range	Percentage of claimed range
Jaguar I-Pace	470 km	359 km	76%
Nissan Leaf	385 km	334 km	87%
Mercedes-Benz EQC	417 km	312 km	75%
Audi e-tron	410 km	332 km	81%
Kia e-Niro	454 km	410 km	90%
Tesla Model 3 LR	560 km	435 km	78%

EVs convert over 77% of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 12%–30% of the energy stored in gasoline to power at the wheels. This is the reason why electric vehicles are more efficient than gasoline/diesel powered cars.

1.5. Comfort

Most EV's lack in this area. They usually have stiffer suspension and bigger tyres to compensate the high weight. However this plus the low centre gravity gives these cars very good handling in the turns. However, one of the first things drivers notice when switching to an electric car is the quietness of the vehicle, which creates a comfortable, relaxing driving experience. Batteries in EVs are often found in the floor of the car, which provides excellent balance and weight distribution. This means handling around corners and curves is effortless and reliable.

1.6. Running costs

While the price of an EV may be higher than comparable petrol or diesel cars, the cost of running one is significantly cheaper particularly over the full lifetime of the vehicle. From tax incentives and special government grants to enhanced fuel efficiency, the lower cost of electricity and reduced maintenance requirements, you could spend far less on an electric vehicle than you do on your current car. Fully electric cars are designed to be as efficient as possible and there are generally 3 main components powering the vehicle; the on-board charger, inverter and motor. This means there is far less wear and tear on the car and little stress on the motor, with fewer moving parts susceptible to damage. All this means you'll rarely have to have your EV serviced and the running and repair costs are minimal.

1.6.1 Cost of charging at public stations

The cost of charging your electric car at a public charge point depends on the charge point network and the location of the charge point. Many local authorities offer a pay per session approach to on-street chargers. Occasionally they can be free to use if you have access to a network subscription. Public charge point costs also vary depending on the power rating and whether it's slow (lamppost charging), fast (Car parks) or Rapid (Motorway service stations).

Rapid charge points are typically found at motorway service stations and can also be free for certain drivers but are generally seen as one of the more expensive options. In essence, because they offer a faster charge (drivers can typically charge an electric car to 80% in 20-40 mins) and greater convenience, they tend to come at a premium. Pod Point rapid chargers cost 23p/kWh at Lidl and 24p/kWh at Tesco, which is about £6-7 for 30 minutes of charging (about 160 kilometres of range).

1.6.2 Cost of charging at home

Charging your electric car at home is the main charging option for most EV owners. It's important to be on the best home energy tariff to keep this cost as low as possible, because the cost of charging will be included in your normal electricity bill. The cost of installing a home charge point is around £1,000. For instance, if you travel 13,000 kilometres per year in your car, this might equate to around 2800 kWh of additional electricity on your yearly bill if 1 kWh equals 5.6 kilometres. If we take a price of 20 pence per kWh, you will spend about 465 pound sterling on electricity. The data is in prices for the United Kingdom.

2. The future: Evaluation of the possible effect of EVs on ICEs

2.1 Goals and problems of electric vehicles

The main goal of the switch to electric vehicles is to reduce air pollution. Transportation is the largest source of greenhouse-gas emissions in the US and fourth largest globally, so there is no way to achieve the reductions necessary to avoid dangerous levels of global warming without major shifts to cleaner vehicles and mass transit system. The problem is that the steady decline in the cost of lithium-ion batteries, which power EVs and account for as stated before a third of their total cost, is likely to slow in the next few years as they approach limits set by the cost of raw materials. Current li-ion battery packs are estimated to cost from around 175 to 300 US dollars per kilowatt-hour. If a typical midrange EV has a 60 kWh battery pack, the battery pack will have a price between 10 500 to 18 000 US dollars. By 2025 the price is projected to reach 100 $/kWh

Current data shows that and increasing number of world leading manufacturers around the world are moving into EVs. For example. Audi, Jaguar, Mercedes-Benz, and Tesla have all introduced battery-powered SUVs to cater for consumers' tastes for larger vehicles. As well as those. Many other manufactures have introduced EVs into their product range.

An important MIT study (Temple, 2019) notes that achieving deep reductions in transportation emissions will require a parallel overhaul of the electricity systems used to charge EVs. Currently, US carbon emissions per mile for a battery electric vehicle are on average only about 45% less than those from a gas-fuelled vehicle of comparable size. However, EVs in some US regions, notably including coal states like West Virginia, could generate nearly the same level of emissions as standard vehicles over their lives. In parts of India and China with particularly dirty electricity systems, EVs may even generate more emissions than gas-fueled vehicles, says Emre Gencer, a research scientist who worked on the study.

The MIT study projects that the share of electric vehicles will rise in any scenario, reaching 35% of the global vehicle fleet by 2040 as prices slowly decline, even with no additional climate polices. But a strong set of additional regulations, including a global carbon tax set high enough to prevent 2 ˚C of warming, would push that figure to 50% by 2050.

2.2. Why are internal combustion engines far from dead?

The internal combustion engine is still incredibly relevant today, and can still use further improvements in order to reduce global emissions. One advantage of petrol over batteries is energy density. For example 3.8 litres of petrol it would have the equivalent of 33.8 kWh of energy in that volume. This means the battery of the first-generation Nissan Leaf has less energy stored that 3.8 litres of gasoline.

Batteries have improved since then. Nowadays, the best energy density lithium-ion battery cell stored 684 wh/l, which means it would take a volume of 70 litres to conserve the same energy of 33.8 kWh of 3.8 litres of petrol. Simply explained, by volume petrol is 13 times more energy dense that the best li-ion batteries. Yes, electric vehicles consume less energy that a petrol vehicle, but the volume and weight of batteries is still an area in which manufactures need to improve.

CONCLUSION

Electric vehicles are still very far from taking over cars with internal combustion engines. As disclosed, EVs are predicted to reach 35% of all new vehicles sales by 2040 and to be at the level of ICE vehicles, electric cars are expected to reach 50% of new vehicles sales by 2050. But that is still 20-30 years from now and a lot can change. Some production limitations might be found which would delay the overtake.

On the other hand some new technologies might be discovered which could mean a sooner increase electric vehicle sales.

A definite answer to the question if electric vehicles will take over cannot be given, because all data and information for the future are only expectations and predictions.

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WED-ONLINE-SSS-MEMBT-04

3D PRINTER FILAMENTS MADE FROM RECYCLED PLASTICS

Emili Todorova – Student
Department of Mechanical Engineering
University of Ruse "Angel Kanchev"
Tel.: +373 877 312 119
E-mail: emilytodorova_1900@abv.bg

Abstract: *The paper reviews existing methods of recycling and discloses the possibility of utilizing plastic waste as useful materials in 3D printing. In particular it examines there possible use as filament or powdered plastics used in different 3D printing methods and compares their effectiveness.*

Keywords: *Efficiency, Effectiveness, GPS, Seismic Protection Methods, Model*

INTRODUCTION

The plastics industry began in the early 1900s when the first synthetic plastic was created by Leo Hendrik Baekeland in the U.S. Since the industry began, annual global plastic production has exploded from some 1.5 million metric tons in 1950 to 359 billion metric tons in 2018. The cumulative production of plastic has already surpassed eight billion metric tons worldwide, with further increases expected in the coming decades.
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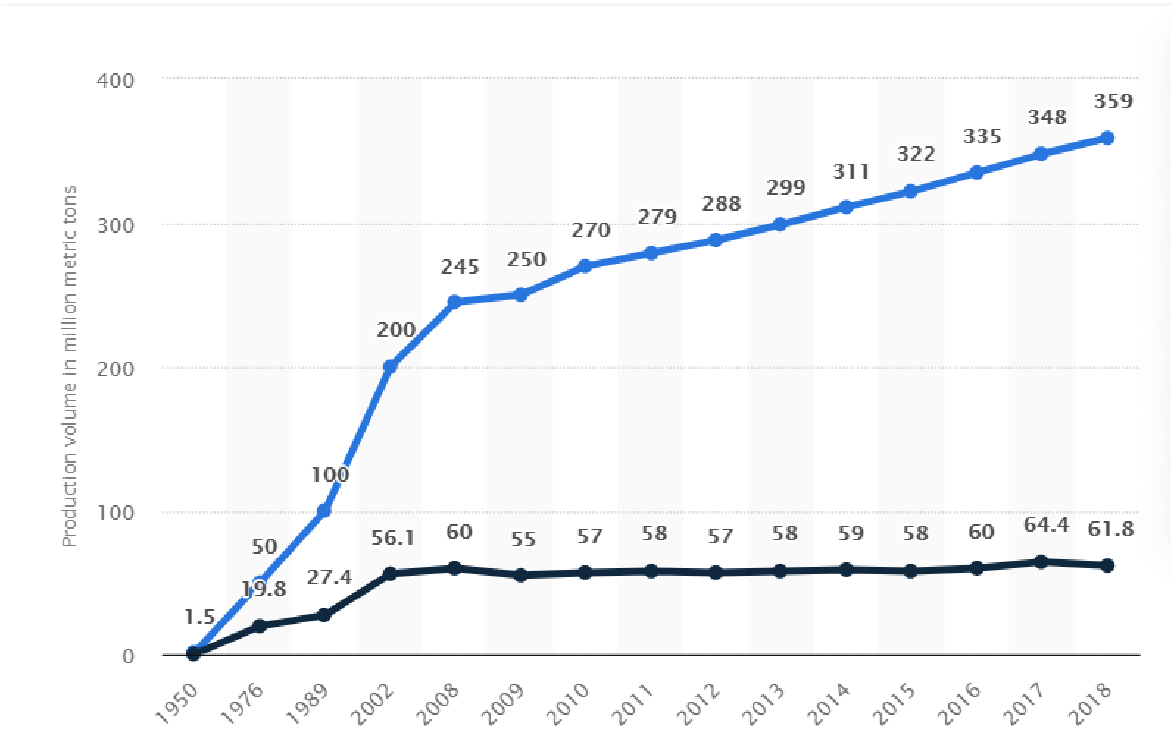


*Fig.1 Production of plastics worldwide from 1950 to 2018 (in million metric tons)**

We talk about "plastic" as though it's a single material, but there are in fact many different plastics. What they have in common is that they're plastic, which means they are soft and easy to turn into many different forms during manufacture. Plastics are synthetic (human-made) materials, made from polymers, which are long molecules built around chains of carbon atoms, typically with hydrogen, oxygen, sulfur, and nitrogen filling in the spaces. You can think of a polymer as a big molecule made by repeating a small bit called a monomer over and over again; "poly" means many, so "polymer" is simply short for "many monomers." If you think of how a long coal train is made from many trucks coupled together, that's what polymers are like. The trucks are the monomers and the entire train, made from lots of identical trucks, is the polymer. Where a coal train might have a couple of dozen trucks, a polymer could be built from hundreds or even thousands of monomers. In other words, polymers typically have very large and heavy molecules.

Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products. Since the majority of plastic is non-biodegradable.

3D printing, also called additive manufacturing, is a family of processes that produces objects by adding material in layers that correspond to successive cross-sections of a 3D model. Plastics and metal alloys are the most commonly used materials for 3D printing, but it can work on nearly anything—from concrete to living tissue.

EXPOSURE

<u>Types of Plastic</u>

***Common plastics**

Polyamides (PA) or (nylons)

Polycarbonate (PC)

Polyester (PES)

Polyethylene (PE)

High-density polyethylene (HDPE)

Low-density polyethylene (LDPE)

Polyethylene terephthalate (PET)

Polypropylene (PP)

Polystyrene (PS)

High impact polystyrene (HIPS)

Polyurethanes (PU)

Polyvinyl chloride (PVC)

Polyvinylidene chloride (PVDC)

Acrylonitrile butadiene styrene (ABS)

Polycarbonate+Acrylonitrile Butadiene Styrene (PC+ABS)

Polyethylene+Acrylonitrile Butadiene Styrene (PE+

***Specialist plastics/ High-performance plastics**

Polyepoxide (epoxy)

Polymethyl methacrylate (PMMA) (acrylic)

Polytetrafluoroethylene (PTFE), or Teflon

Phenolics or phenol formaldehyde (PF)

Melamine formaldehyde (MF)

Urea-formaldehyde (UF)

Polyetheretherketone (PEEK)

Maleimide/bismaleimide

Polyetherimide (PEI) (Ultem)

Polyimide

Plastarch material

Polylactic acid (PLA)

Furan

Silicone poly

Polysulfone

Polydiketoenamine (PDK).

***Types of 3D printing .**

The reasons there are different types of 3D printers and printing processes, it all comes down to the following six considerations:

^Printer cost

^Print quality

^Print speed

^Printer capability

^Practicality

^User expectations

1) Stereolithography (SLA) Technology

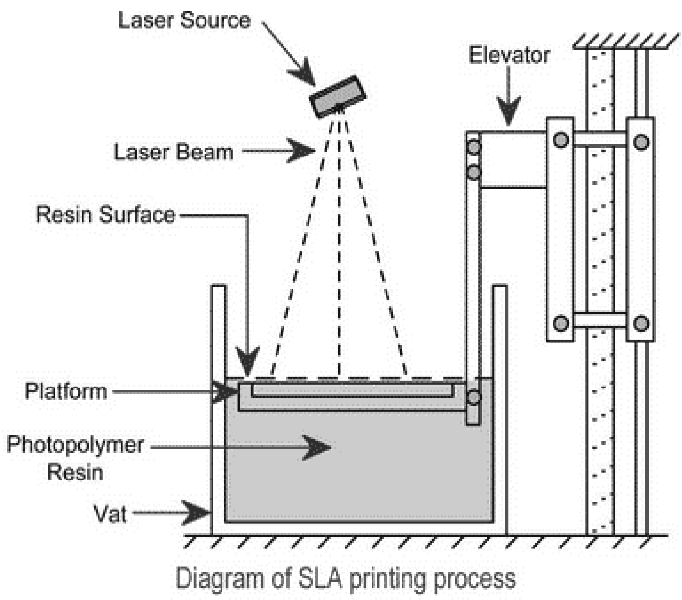


Fig.2 **Stereolithography (SLA) Technology**

SLA is a fast prototyping process. Those who use this technology are serious about accuracy and precision. It can produce objects from 3D CAD data (computer-generated) files in just a few hours. This is a 3D printing process that's popular for its fine details and exactness. Machines that use this technology produce unique models, patterns, prototypes, and various production parts. They do this by converting liquid photopolymers (a special type of plastic) into solid 3D objects, one layer at a time. The plastic is first heated to turn it into a semi-liquid form, and then it hardens on contact. The printer constructs each of these layers using an ultra violet laser, directed by X and Y scanning mirrors. Just before each print cycle, a recoater blade moves across the surface to ensure each thin layer of resin spreads evenly across the object. The print cycle continues in this way, building 3D objects from the bottom up.

2) Digital Light Processing (DLP) Technology

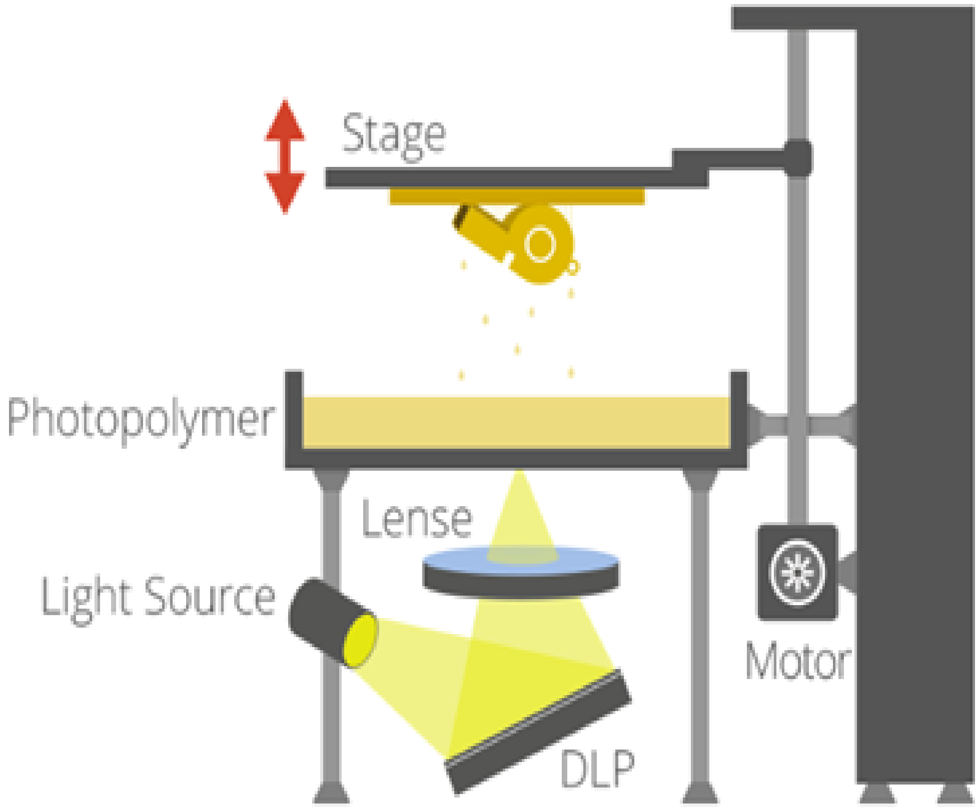
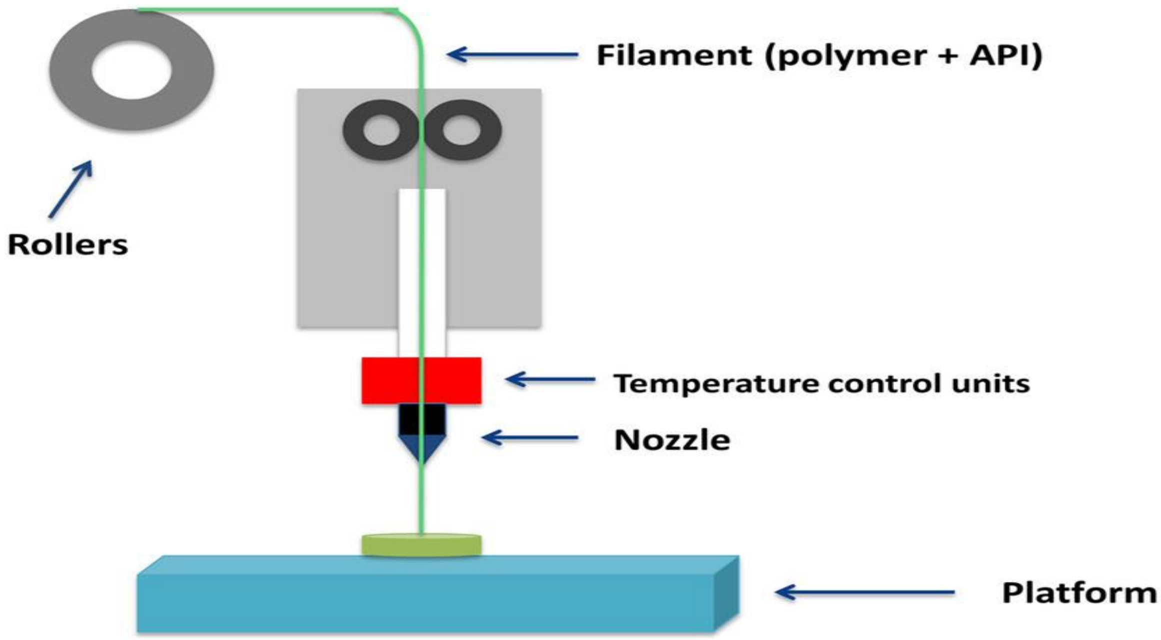


Fig.3 Digital Light Processing (DLP) Technology

DLP is the oldest of the 3D printing technologies, created by a man called Larry Hornbeck back in 1987. It's similar to SLA (see above), given that it also works with photopolymers. The liquid plastic resin used by the printer goes into a translucent resin container. There is, however, one major difference between the two, which is the source of light. While SLA uses ultra violet light, DLP uses a more traditional light source, usually arc lamps. This process results in pretty impressive printing speeds. When there's plenty of light, the resin is quick to harden (we're talking seconds). Compared to SLA 3D printing, DLP achieves quicker print times for most parts. The reason it's faster is because it exposes entire layers at once. With SLA printing, a laser has to draw out each of these layers, and this takes time**.**

3) Fused Deposition Modeling (FDM) Technology



Fused Deposition Modeling (FDM) Technology

FDM is a 3D printing process developed by Scott Crump, and then implemented by Stratasys Ltd., in the 1980s. It uses production grade thermal plastic materials to print its 3D objects. It's popular for producing functional prototypes, concept models, and manufacturing aids. It's a technology that can create accurate details and boasts an exceptional strength to weight ratio. Before the FDM printing process begins, the user has to slice the 3D CAD data (the 3D model) into multiple layers using special software. The sliced CAD data goes to the printer which then builds the object layer at a time on the build platform. It does this simply by heating and then extruding the thermoplastic filament through the nozzle and onto the base. The printer can also extrude various support materials as well as the thermoplastic. For example, as a way to support upper layers, the printer can add special support material underneath, which then dissolves after the printing process. As with all 3D printers, the time it takes to print all depends on the objects size and its complexity.

4) Selective Laser Sintering (SLS) Technology

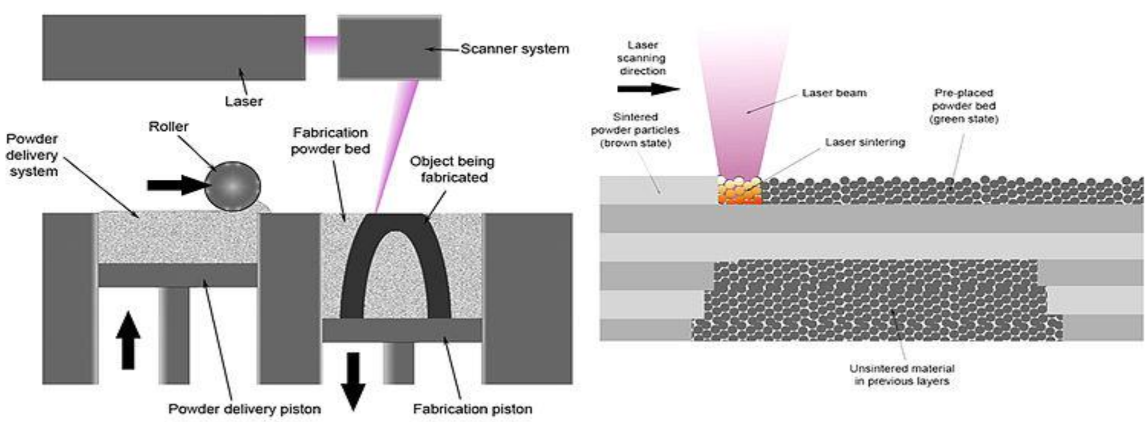


Fig. 4 Selective Laser Sintering (SLS) Technology

An American businessman, inventor, and teacher named Dr. Carl Deckard developed and patented **SLS** technology in the mid-1980s. It's a 3D printing technique that uses high power CO2 lasers to fuse particles together. The laser sinters powdered metal materials (though it can utilize other materials too, like white nylon powder, ceramics and even glass). Here's how it works:The build platform, or bed, lowers incrementally with each successive laser scan. It's a process that repeats one layer at a time until it reaches the object's height. There is un-sintered support from other powders during the build process that surround and protect the model. This means the 3D objects don't need other support structures during the build. Someone will remove the un-sintered powders manually after printing. SLS produces durable, high precision parts, and it can use a wide range of materials. It's a perfect technology for fully-functional, end-use parts and prototypes. SLS is quite similar to SLA technology with regards to speed and quality. The main difference is with the materials, as SLS uses powdered substances, whereas SLA uses liquid resins. It's this wide variety of available materials that makes SLA technology so popular for printing customized objects.

5) Selective Laser Melting (SLM) Technology

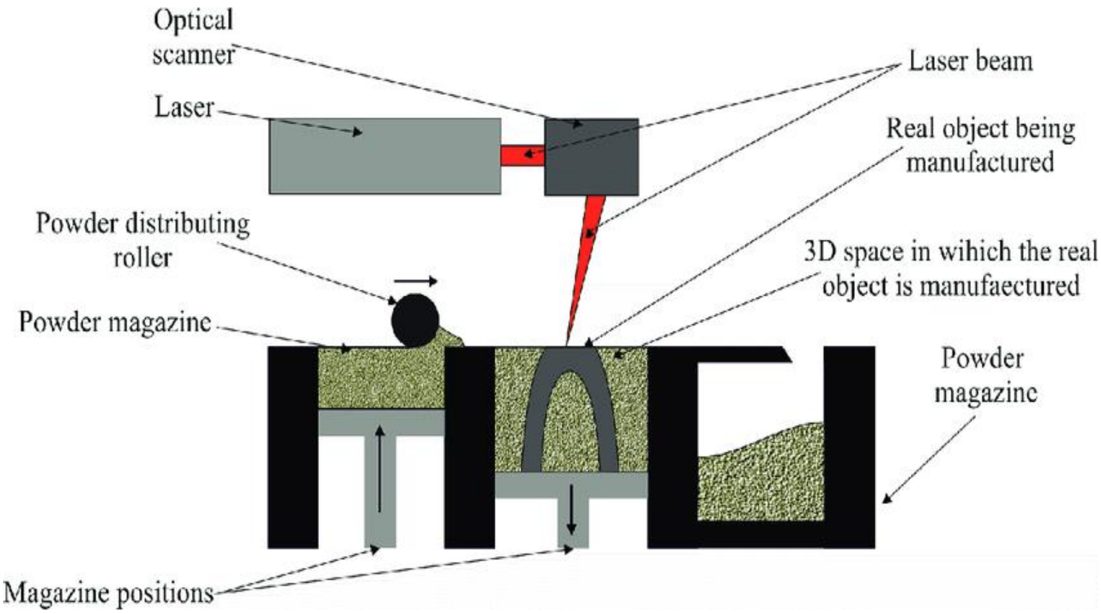


Fig. 5 Selective Laser Melting (SLM) Technology

SLM made its debut appearance back in 1995. It was part of a German research project at the Fraunhofer Institute ILT, located in the country's most western city of Aachen. Like SLA (see above), SLM also uses a high-powered laser beam to form 3D parts. During the printing process, the laser beam melts and fuses various metallic powders together. The simple way to look at this is to break down the basic process like thus:

Powdered material + heat + precision + layered structure = a perfect 3D object.

As the laser beam hits a thin layer of the material, it selectively joins or welds the particles together. After one complete print cycle, the printer adds a new layer of powered material to the previous one. The object then lowers by the precise amount of the thickness of a single layer. When the print process is complete, someone will manually remove the unused powder from the object. The main difference between SLM and SLS is that SLM completely melts the powder, whereas SLS only partly melts it (sinters). In general, SLM end products tend to be stronger as they have fewer or no voids. A common use for SLM printing is with 3D parts that have complex structures, geometries and thin walls. The aerospace industry uses SLM 3D printing in some of its pioneering projects. These are typically those which focus on precise, durable, lightweight parts. It’s a costly technology, though, and so not practical or popular with home users for that reason. SLM is quite widespread now among the aerospace and medical orthopedics industries. Those who invest in SLM 3D printers include researchers, universities, and metal powder developers. There are others too, who are keen to explore the full range and future potential of metal additive manufacturing in particular.

6) Electron Beam Melting (EBM) Technology

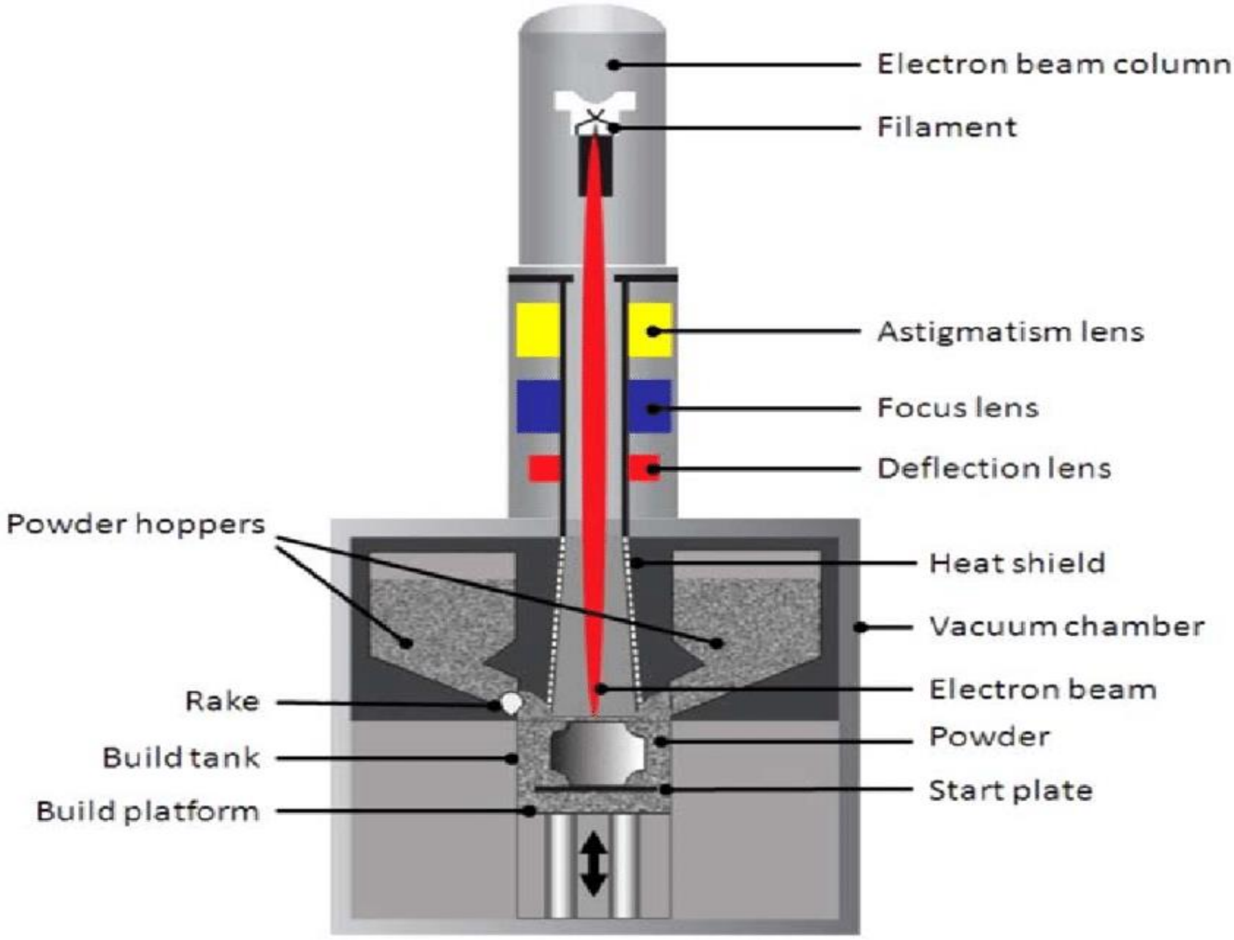


Fig.6 Electron Beam Melting (EBM) Technology

A Swedish company called Arcam AB founded EBM® in 1997. This is a 3D printing technology similar to SLM (see above), in that it uses a powder bed fusion technique. The difference between the two is the power source. The SLM approach above uses high-powered laser in a chamber of noble, or inert gas. EBM, on the other hand, uses a powerful electron beam in a vacuum. Aside from the power source, the remaining processes between the two are quite similar. EBM’s main use is to 3D print metal parts. Its main characteristics are its ability to achieve complex geometries with freedom of design. EBM also produces parts that are incredibly strong and dense in their makeup.

Some of EBM’s other features are:

Doesn’t need extra auxiliary equipment for the 3D printing process

Has increased efficiency using raw materials

Lessens lead times resulting in parts getting to market faster

Can create fully functional, durable parts on demand for wide-ranging industries

The printing process starts like most others in that the user has to first create a 3D model, or computer-generated digital file.

7) Laminated Object Manufacturing (LOM) Technology

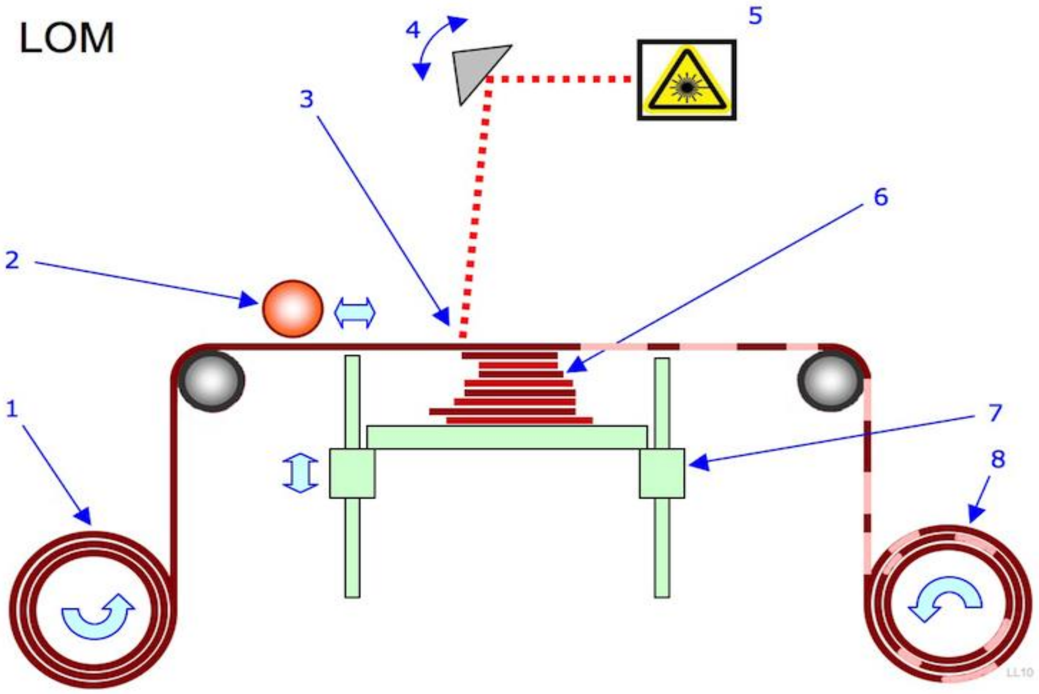


Fig. 7 Laminated Object Manufacturing (LOM) Technology

A Californian company called Helisys Inc. (now Cubic Technologies), first developed LOM as an effective and affordable method of 3D printing. A US design engineer called Michael Feygin—a pioneer in 3D printed technologies—originally patented LOM.

LOM is a rapid prototyping system that works by fusing or laminating layers of plastic or paper using both heat and pressure. A computer-controlled blade or laser cuts the object to the desired shape. Once each printed layer is complete, the platform moves down by about 1/16th of an inch, ready for the next layer. The printer then pulls a new sheet of material across the substrate where it's adhered by a heated roller. This basic process continues over and over until the 3D part is complete. It might not be the most popular method of 3D printing today, but LOM remains one of the fastest nonetheless. It's also perhaps the most affordable method for creating 3D prototypes. The reason for this is because of the low cost of materials used (papers and plastics). It's also a process that can create fairly large 3D printed objects. Those who continue to use LOM printers today include architects, artists, and product developers.

8) Binder Jetting (BJ) Technology

The Massachusetts Institute of Technology (MIT) first invented BJ 3D printing. You may also hear this technology referred to in other names, including:

Powder bed printing

Inkjet 3D printing

Drop-on-powder

BJ is a 3D printing process that uses two types of materials to build objects: a powder-based material (usually gypsum) and a bonding agent. As the name suggests, the "bonding" agent acts as a strong adhesive to attach (bond) the powder layers together. The printer nozzles extrude the binder in liquid form similar to a regular 2D inkjet printer. After completing each layer, the build plate lowers slightly to allow for the next one. This process repeats until the object reaches its required height.

Popular materials used in BJ printing include:

Ceramics

Metals

Sand

Plastics

It’s not possible to get super high-resolution or overly rugged 3D objects with BJ printing, but there are other advantages. For example, these printers allow you to print parts in full color. To do this, you simply add color pigments to the binder, which typically include black, white, cyan, yellow, and magenta. This technology is still advancing, so expect more great things to come in the future. At the time of writing, some applications of BJ 3D printing include rapid prototyping, and various uses in the aerospace, automotive, and medical industries.

9) Material Jetting (MJ) Polyjet and Wax Casting Technology

You will also hear Material Jetting referred to as wax casting. Unlike other 3D printing technologies, there isn’t a single inventor for MJ. In fact, up until recent times it’s been more of a technique than an actual printing process. It’s something jewelers have used for centuries. Wax casting has been a traditional process where the user produces high-quality, customizable jewelry. The reason it gets a mention here is because of the introduction of 3D printing. Thanks to the arrival of this technology, wax casting is now an automated process. Today, MJ 3D printers produce high-resolution parts, mainly for the dental and Jewelry industries, For jewelers who want to experiment with various casts—as most jewelers do—MJ is now their leading 3D technology. At the time of writing, there are a few high-quality professional wax 3D printers on the market. Here’s how they work: Once the 3D model (CAD file) is uploaded to the printer, it’s all systems go. The printer adds molten (heated) wax to the aluminum build platform in controlled layers. It achieves this using nozzles that sweep evenly across the build area. As soon as the heated material lands on the build plate it begins to cool down and solidify (UV light helps to cure the layers). As the 3D part builds up, a gel-like material helps to support the printing process of more complex geometries. Like all support materials in 3D printing, it’s easy to remove it afterward, either by hand or by using powerful water jets. Once the part is complete you can use it right away, no further post-curing necessary.

There are also Polyjet MJ 3D printers, which use photopolymer-resins rather than synthetic waxes. Polyjet technology also offers very good resolution. Unlike digital wax printers, people use Polyjet devices to create parts for a wide range of industries.

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CONTEMPORARY APPLICATIONS OF ADDITIVE MANUFACTURING

Iliya Iliev – Student
Department of Machine Tools and Manufacturing,
University of Ruse "Angel Kanchev"
Tel.: +359 89 761 3630
E-mail: s201031@stud.uni-ruse.bg

Abstract: *The publication presents an aspect of the current level of machine manufacturing and introduces the metal additive manufacturing process as an innovative way of creating different parts. This new method allows the producer to make countless objects in various shapes and the only limit is the imagination. The process of part creation has changed over the years. Nowadays more and more companies prefer the 3D printing method to satisfy their needs. Using a specific software, engineers can develop a wide variety of objects which can be used in the machine manufacturing process. With the help of 3D printing mechanical engineers can develop their products much faster and the whole building process can be simplified.*

Keywords: *Additive manufacturing, mechanical engineering, machines, machine manufacturing, 3D printing, metal parts, metal 3D printing, engineering, mechanical engineering*

INTRODUCTION

Mechanical Engineering as a process and technology overall has evolved during the years. In the early centuries, people used forging and casting to form their metals in different shapes. Later they discovered new ways to process the metal and they started building machines. By that the work improved significantly and the process was faster and much more precise. Those machines changed in time and the productivity increased. More and more features were invented and the technology of metal forming evolved. Nowadays there are various methods to get the desired shape of a metal part. One of the newest methods to create a detail is by metal 3D printing. With the help of a specific software and a printer of that kind, engineers can achieve almost any form and level of detail which is required.

EXPOSITION

3D printing is relatively new to the machine engineering industry. The usual materials used to print 3D objects are polymers due to the ease of manufacturing. In the last few years this method has evolved rapidly and this kind of development was introduced to the metalworking industry. One of the main advantages of 3D printing is design freedom. With the use of technology various forms can be created out of a single metal or metal alloys. It is scientifically shown that under certain conditions the final 3D printed stainless steels are up to three times stronger than steels made by conventional techniques and yet still ductile. Unfortunately due to the flexibility this method is still expensive, which is why some companies still prefer to use the CNC processing to create most of their details. Another limitation to additive manufacturing is the size of the part. The maximum build size of most 3D printers is around $200mm^3$. However, technology evolves and many car companies, for example, opt for 3D printed details for their vehicles. The printers used are usually larger and more efficient. Every metal 3D printed part requires some form of post processing. This includes power removal, heat treatment or post machining which adds cost and time of production.

The additive manufacturing process is not simple. There is a lot of preparation required before the actual detail creation.

The first stage of the process is creating a 3D model with the use of CAD (Computer-aided design) software (Fig.1). All additive manufacturing parts should first be visualised as a software model that fully describes their external geometry. The output, however, must be a 3D solid or surface representation.

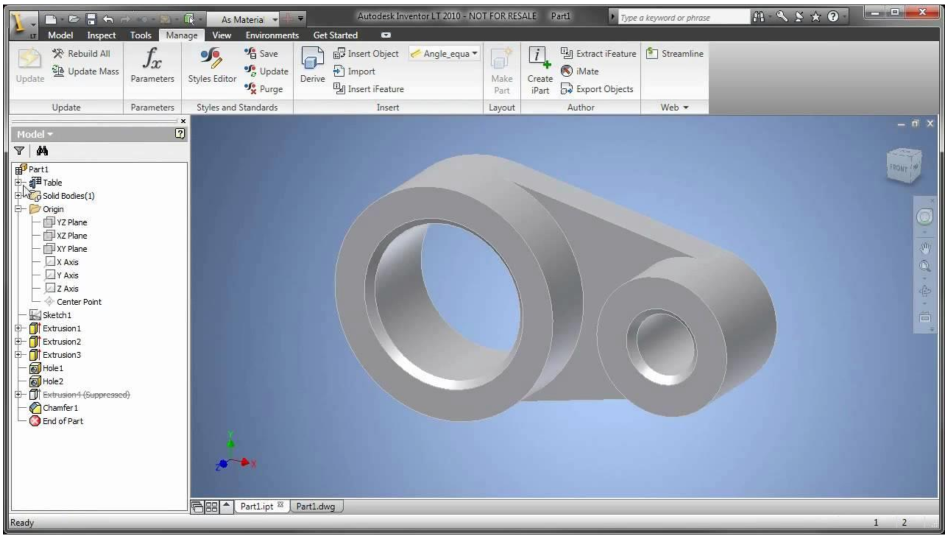

Fig. 1. Example of a part, created in Autodesk Inventor 2019.

The next step is converting the model to a file which can be read by the processing machine. The usual format of those files is .STL (Fig. 2). This is a file format native to the stereolithography CAD software created by 3D Systems. STL has several backronyms such as "Standard Triangle Language" and "Standard Tessellation Language". Nowadays nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

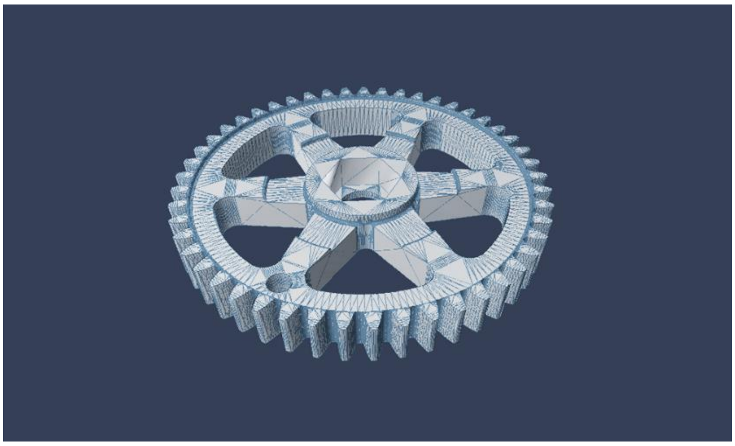

Fig. 2. STL model example.

Step №3 is transferring the final file to the machine and manipulation. To properly do the detail, there is a set up that needs to be done before the beginning of the actual creation. The file needs to be adjusted so that the model is the correct size, position, and orientation for building.

After that there is a machine set up process which includes layer thickness, material constraints, energy source, timings, etc. Engineers need to specify the metal used for the detail and properly set the printer to work.

When the settings are done, the machine can now start the building process. Only one operator is needed to monitor the machine. His task is to keep an eye on the process and assure no errors have taken place like running out of material, power or software glitches.

When the actual creating process is done, the parts need to be removed. This often requires interaction with the machine. The operator should ensure that the machine is stopped and there are no moving parts. The next thing which has to be checked is if the temperatures are low enough so there are no injuries during the contact between the detail and the person.

After the details are taken out of the printer, they should be carefully examined before they are ready for use. As previously said some parts may need additional heat treatment or at least cleaning up before application.

The last and final step is application. Some parts may now be ready (Fig. 3). However, they may also require additional treatment before they are acceptable for use. Smoothing, priming and painting may be needed to reach the desired surface texture and finish. Treatments may be difficult and even time-consuming if the finishing requirements are very demanding. Some details may need to be assembled together with other mechanical or electronic components.

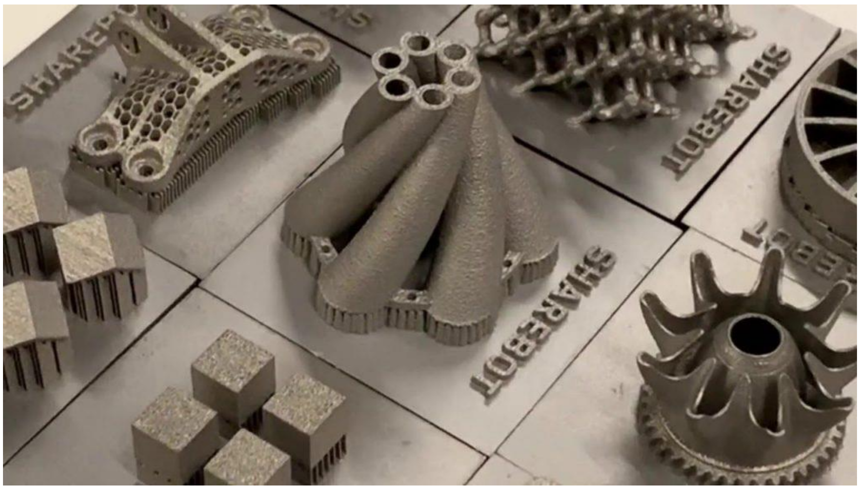

Fig. 3. 3D details after the building process.

Additive manufacturing can be used in many branches. For example 3D printing finds application in the automobile industry. Mercedes-Benz revealed first metal 3D Printed truck part (Mercedes-Benz 1883). Ford produced the largest ever 3D printed metal automotive part. It has been installed in the “Hoonitruck”, a 1977 Ford F-150 with a twin-turbo 3.5-litre V6 EcoBoost engine owned by Ken Block, star of popular YouTube series, Gymkhana (FordPerformance 2019). Bugatti made their Divo model with 44 3D printed parts. They used 3D printed titanium brake calipers for their vehicle with dimensions: 410 x 210 x 136 mm. (Bugatti 2019)   Additive manufacturing is used even in Aerospace technologies. A leading metal 3D printing company in the Additive Manufacturing market, called InssTek (InssTek 2016), builds rocket fuel tanks and rocket nozzles. Moreover, they repair Jet engine air seals and compressor blades for the turbines using titanium alloy (Ti-6AI-4V).

In medicine 3D printers are used to create artificial joints using special materials.

Additive manufacturing has potential to be used in every industry. Everything is possible using suitable material and a 3D printer. Engineers are able to combine materials to reach the desired strength and reliability of the detail. Here are some of the preferred materials and their positive and negative sides. (Varotsis n.d.)

Table 1. Some of the metals used for 3D printing.

	Material
Aluminium alloys	⊕ Good mechanical & thermal properties ⊕ Low density ⊕ Good electrical conductivity ⊖ Low hardness
Stainless steel & tool steel	⊕ High wear resistance ⊕ Great hardness ⊕ Good ductility and weldability
Titanium alloys	⊕ Corrosion resistance ⊕ Excellent strength-to-weight ratio ⊕ Low thermal expansion ⊕ Biocompatible
Cobalt-Chrome superalloys	⊕ Excellent wear & corrosion resistanc ⊕ Great properties at elevated temperatures ⊕ Very high hardness ⊕ Biocompatible
Nickel superalloys (Inconel)	⊕ Excellent mechanical properties ⊕ High corrosion resistance ⊕ Temperature resistant up to 1200ºC ⊕ Used in extreme environments
Precious metals	⊕ Used in jewellery making ⊖ Not widely available

Additive manufacturing has a lot in common with the CNC (Computer Numerical Control) machining technology. CNC is another computer-based technology that is used to manufacture products. The main difference is that it subtracts material rather than adding it on layers. CNC machines require a block of material that must be at least as big as the detail that is needed. In terms of speed CNC machining is much faster than the additive manufacturing but while 3D printing makes the part in one stage, CNC may often require repositioning or relocating the detail, which is also time consuming. Both methods handle well in terms of accuracy but the precision of CNC machines is dependent on the diameter of the rotary cutting tools and the exact position of the block. In any case the machines should be programmed before the building process begins. If there is some kind of a problem CNC machines are more likely to cause damage and even expose human safety on risk. Despite those facts, people still prefer the CNC machining because it is the cheaper way to create a detail, without sacrificing reliability or strength. (Gibson, Rosen and Stucker 2010)

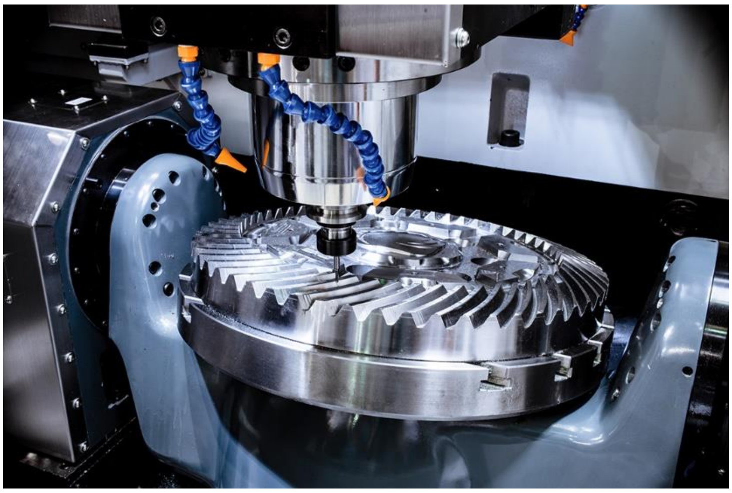

Fig. 4. Detail processing using the CNC method.

A company called SpaceCAD (SpaceCAD 1996), based in Bulgaria uses both methods to create their products. They work with companies such as Siemens and they offer lessons for both Additive manufacturing and CNC machining.

CONCLUSION

3D printing machines are slowly making their way into homes, businesses, disaster sites, and even outer space. Additive manufacturing has the potential to prevail in the production of goods, from food to medical supplies, to great coral reefs. The popularity of 3D printing increases as it is the safer method to create parts. In the near future people may realise how useful this technology can be and they will strive to use it into their daily lives.

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