How It's Made: A Manufacturing Processes Analysis

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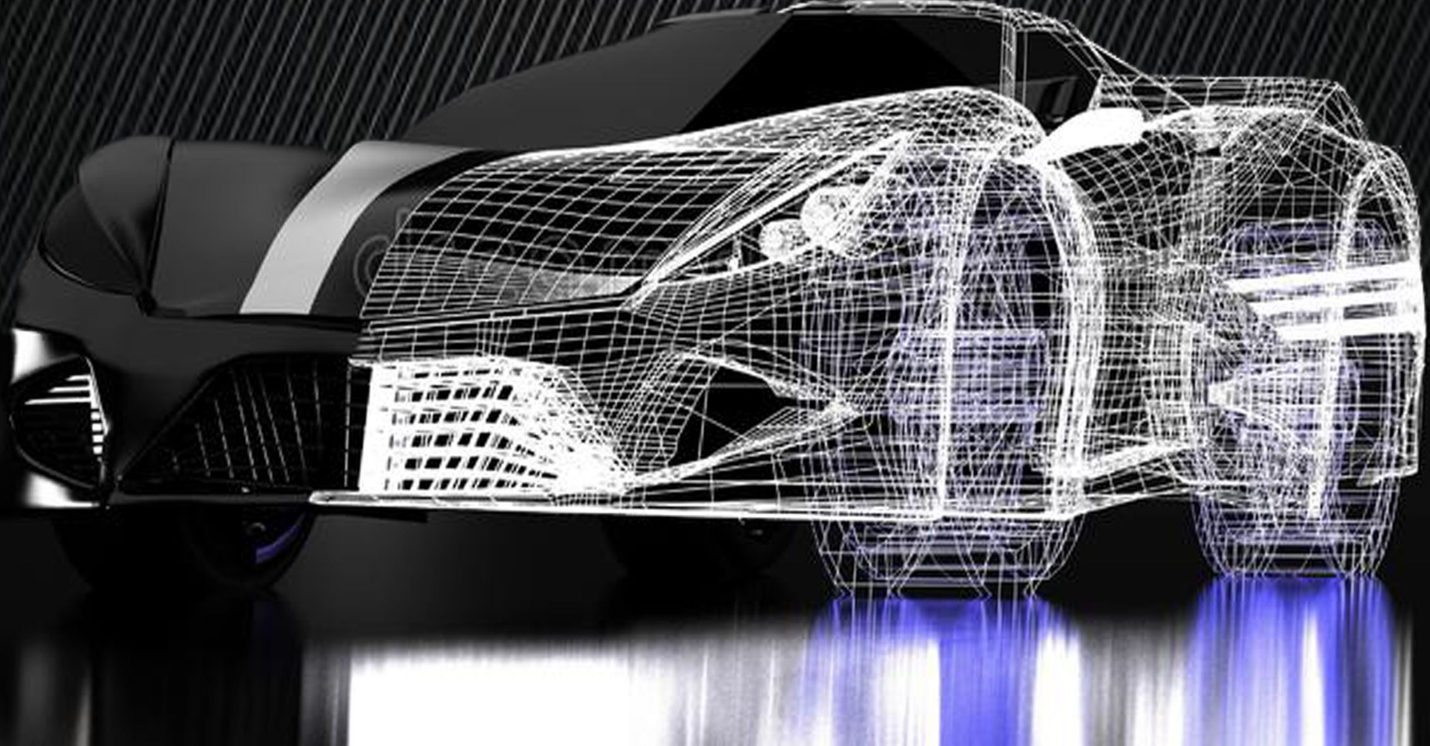

HOW ITS MADE: A MANUFACTURING PROCESSES ANALYSIS

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Dated: 23 December 2020

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Dated: 23 December 2020

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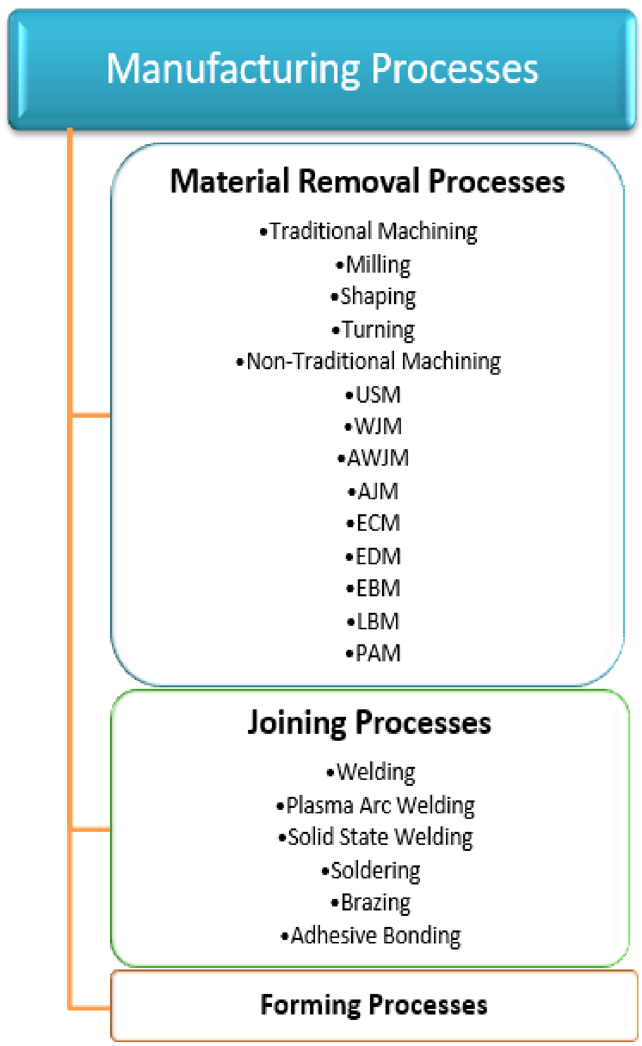
<u>Manufacturing Processes: How It's Made?</u>

The word manufacture is derived from two Latin words, manus (hand) and factus (make); the combination means made by hand. manufacturing can be defined two ways, one technologic and the other economic. Technologically, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products; manufacturing also includes assembly of multiple parts to make products. The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labor. Manufacturing is almost always carried out as a sequence of operations. Each operation brings the material closer to the desired final state. Economically, manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations. There exist a large number of conventional manufacturing processes which are used for the manufacturing of common products. However, the manufacturing engineering is a dynamic field marked with continuous advancement in the traditional approaches and the incorporation of novel approaches for manufacturing advanced products. Not all manufacturing processes can produce a product with equal ease, quality, and economy. Each manufacturing process is generally characterized by some advantages and limitation over the other processes. There are several manufacturing processes currently used in industries. It is convenient to discuss the manufacturing processes by grouping them into certain classes based on some characteristic common features.

The Manufacturing Processes are commonly divided as shown in figure.



Material Removal Processes

Material is removed in this process to make the desired part. It is further divided into two categories:

Traditional and Non-traditional

Traditional or conventional machining includes sharp cutting edges of tools and shearing action while non-traditional machining use energy instead of cutting edges and no shear force is used in removing of material. The non-traditional processes are further divided into:

- Mechanical (erosion, disintegration)
- Electrical (electrolysis)
- Thermal (fusion, vaporization)
- Chemical (chemical reactions)

Joining Processes

The joining processes include the coalescence of more than one part by use of either heat or pressure. The joining processes also include the assembly of parts using nuts, bolts, screws etc. They are not mentioned as they are not in the context of this report. Welding is the important part of joining processes and it will be discussed in the coming section.

Forming Processes

Bulk Forming are the Cold working processes which includes the plastic deformation of metals below the recrystallization temperature. In most cases, such cold forming is done at room temperature. The major cold-working operations can be classified basically as squeezing, bending, shearing, and drawing.

Problem Statement

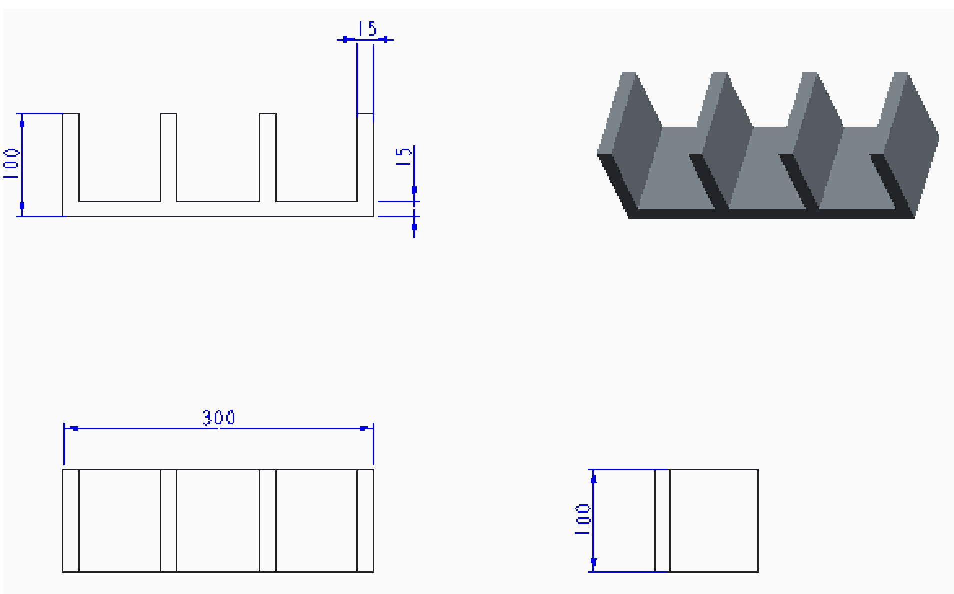
Objective

To analyze different manufacturing processes which can be used to manufacture the given component and select the most suitable process keeping in view the requirements and limitations.

Manufacturing Requirements and Limitations

- No. of parts: 100
- Cost should be low
- CO_2 emissions should be low
- Energy consumption must be minimum
- Part accuracy must be high

Component Design and drawings



Note: All dimensions are in millimeters.

Material of the component

The material is assumed to be of Aluminum Alloy 1050. Aluminum alloy 1050 is a popular grade of aluminum for general sheet metal work where moderate strength is required. It is known for its excellent corrosion resistance, high ductility, and highly reflective finish. The fabrication properties are mentioned in table below.

Fabrication
Workability – Cold: Excellent
Machinability: Poor
Weldability – Gas: Excellent
Weldability – Arc: Excellent
Weldability – Resistance: Excellent
Brazability: Excellent
Solderability: Excellent

Composition

Alloy 1050A	Spec: BS EN 573-3:2009
Chemical Element	**% Present**
Manganese (Mn)	0.0 - 0.05
Iron (Fe)	0.0 - 0.40
Copper (Cu)	0.0 - 0.05
Magnesium (Mg)	0.0 - 0.05
Silicon (Si)	0.0 - 0.25
Zinc (Zn)	0.0 - 0.07
Titanium (Ti)	0.0 - 0.05
Other (Each)	0.0 - 0.03
Aluminium (Al)	Balance

Properties

Physical Property	Value
Density	2.71 g/cm³
Melting Point	650 °C
Thermal Expansion	24 x10^-6 /K
Modulus of Elasticity	71 GPa
Thermal Conductivity	222 W/m.K
Electrical Resistivity	0.0282 x10^-6 Ω .m

Sheet - 0.2mm to 6.00mm — Spec: BS EN 485-2:2008

Mechanical Property	Value
Tensile Strength	105 - 145 MPa
Proof Stress	85 Min MPa
Hardness Brinell	34 HB
Elongation A	12 Min %

Physical and Chemical Advantages

- Light weight
- Strong
- High strength-to-weight ratio
- Resilient
- Ductile at low temperatures
- Corrosion resistant
- Non-toxic
- Heat conducting
- Reflective
- Electrically conducting
- Non-magnetic
- Non-sparking
- Non-combustible

Product Advantages

- Attractive appearance
- Wide range of finishes
- Virtually seamless
- Easy to fabricate
- Joinable by various methods
- Complex, integral shapes
- Easy assembly designs
- Precise, close tolerances
- Uniform quality
- Recyclable
- Cost effective
- Freedom of design

Environment Friendly

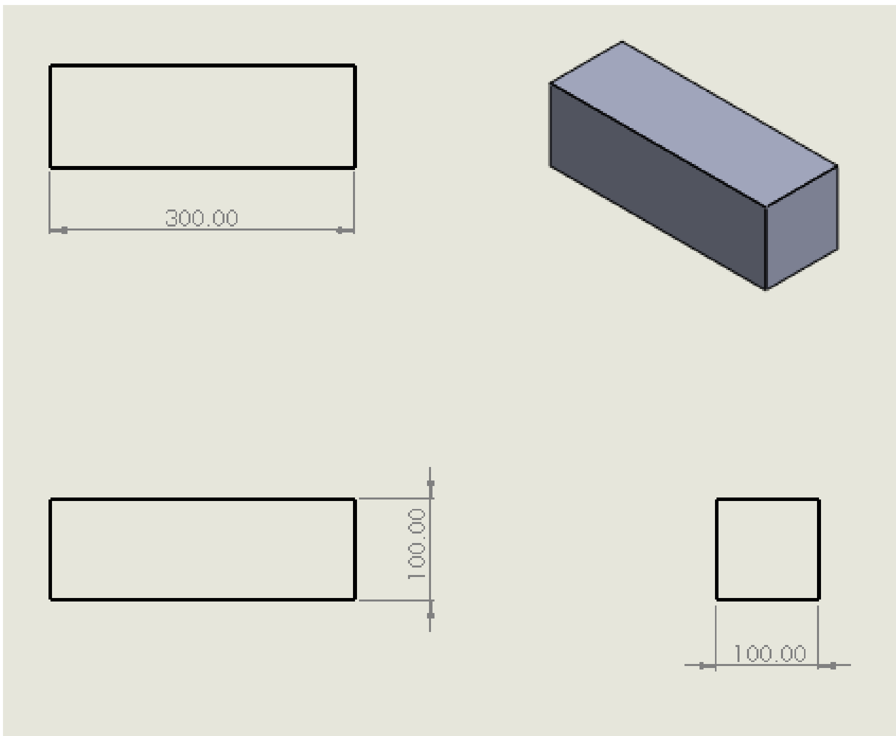
Aluminum itself is nontoxic and odorless. Its surface is smooth, easily washable, and hygienic because no germs can grow on it. Thus, it is widely used in beverage cans, food packaging, cooking utensils and in the fishing and dairy industries.

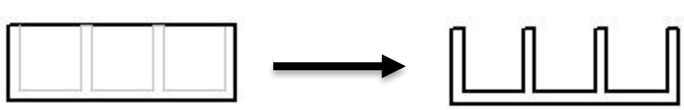
Analysis Methodology

Two Manufacturing methods have been applied for the component:

1) By Material Removal

A block of Aluminum alloy has been taken as the raw material. This block will be transformed to the required part by removing of material by various processes. The dimensions of the block would be $300x100x100mm^3$ as shown in figure below. The slots of $85x80mm^2$ would be cut through it to get the desired shape.





2) By Metal Forming followed by Welding

Using the method of sheet metal forming, four sheets of $100x85mm^2$ and a single sheet of $300x100mm^2$ will be formed using the rolling or extrusion processes. The thickness of both sheets would be 15mm. Afterwards, these sheets will be welded together to form the desired component.

The Potential Processes

The proposed traditional processes are as follows:

1) Shaper Machining

The shaper machine is a reciprocating type of machine which is used to cut material, make slots and other related operations. The shaper holds the single point cutting tool in ram which is in motion while workpiece is fixed in the table.

As the shaper can cut slits through a workpiece, it is a potential process for our design. It will cut the slits of 80x100mm^2 horizontally through the block to a depth of 85mm.

2) Milling

Milling is the process of machining using rotary cutters to remove material by advancing a cutter into a work piece. This may be done varying direction on one or several axes, cutter head speed, and pressure. There are various types of milling machines. For our purpose, the most suitable one is the vertical down milling machine. The workpiece is held horizontally and fed to the rotating cutter tool. It is the most preferred process in traditional machining as there are no vibrations or reciprocating tools as in shaper. It is a smooth process and can be carried out very easily.

Other traditional processes such as drilling, knurling, turning etc. cannot be used as it is a prismatic workpiece. The non-traditional processes are proposed as they can cut through the slits from the block of same dimensions as previously mentioned forming the required workpiece. However, in this case the block is held as the slots will be visible from the top view, so that they can be machined correctly (through cut from above). The non-traditional processes in manufacturing includes:

3) Ultrasonic Machining (USM)

Ultrasonic machining (USM) is a nontraditional machining process in which abrasives contained in a slurry are driven at high velocity against the work by a tool vibrating at low amplitude and high frequency. The main aspects of USM are:

- Workpiece and tool gap > 2 times of grit size.
- Slow process.
- Continuous flow of slurry required.
- High tool wear ratio.
- Preferred for hard materials.

4) Abrasives Water Jet Machining (AWJM)

When WJC is used on metallic work parts, abrasive particles must usually be added to the jet stream to facilitate cutting. AWJM uses a fine, high-pressure, high-velocity stream of water added with abrasives directed at the work surface to cause cutting.

- Grit size: 60 to 120.
- Addition of abrasives in stream: 0.25kg/min.
- Nozzle diameters: 0.25 to 0.63mm.
- Typical standoff distance: ½ of 3.2mm.

5) Electro-Chemical Machining (ECM)

Electrochemical machining removes metal from an electrically conductive workpiece by anodic dissolution, in which the shape of the workpiece is obtained by a formed electrode tool in close proximity to, but separated from, the work by a rapidly flowing electrolyte.

- Material should be a conductor of electricity.
- Insulation of tool required.
- Continuous flow of electrolyte bath.
- Specific Removal Rate (C) for Al: 3.44×10^{-2} mm^3/Amp.sec.
- Gap distance is usually maintained within a range 0.075 to 0.75 mm.
- High power required.
- The electrolytic sludge is hazardous.
- Low tool wear.
- High accuracy.

6) Electric Discharge Machining (EDM)

Electric discharge processes remove metal by a series of discrete electrical discharges (sparks) that cause localized temperatures high enough to melt or vaporize the metal in the immediate vicinity of the discharge.

- Flow of dielectric fluid.
- Pulsating DC supply needed.
- Best surface finish when low currents and high frequencies.
- Tool wear ratio: 1 to 100.

7) Plasma Arc Cutting (PAC)

A plasma is defined as a superheated, electrically ionized gas. The cutting action operates by directing the high-velocity plasma stream at the work, thus melting it and blowing the molten metal through the kerf.

- Workpiece material should be a conductor.
- High operating temperatures (10,000 to 14,000 °C).
- Can cut 150mm thick.
- Specially designed for cutting aluminum and stainless steel.
- High feed rates, thus higher productivity.
- CO_2 is used to stabilize the arc from atmosphere.
- High Noise.

8) Metal Forming and Welding

Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces. Deformation results from the use of a tool, usually called a die in metal forming, which applies stresses that exceed the yield strength of the metal. The metal therefore deforms to take a shape determined by the geometry of the die.

Welding is a fabrication process that joins materials, usually metals or steel, by using high heat to melt the parts together and allowing them to cool, causing fusion.

For the purpose, Rolling, a metal forming process, will be used to convert the large slab of Aluminum to sheets of our desired size which then can be welded by using the most common Gas Metal Arc Welding (GMAW) process. It is not an efficient process but can be used for manufacturing of the component. Some aspects of GMAW are as follows:

- Heavy spattering.
- High productivity.
- Continuity in welding.
- CO_2 is used for ferrous metals.

9) Others (Not suitable processes)

Water jet cutting cannot be used as it is not suitable for cutting metals. Abrasives jet machining is typically used for finishing and toughening of materials. Wire discharge machining cannot be used as the kerf that is cut is so narrow and the longer height of wire is required that should be greater than the height of workpiece which is very difficult to machine. LBM and EBM are used for thin parts ranging from 0.25 to 6.3 mm in thickness. Also, aluminum has a reflective surface that can cause spattering in LBM.

Required Calculations

Volume of Material Removed

One slot:

$$80 \times 100 \times 85 \quad = 680{,}000\ mm^3$$

Three slots should be made in a block:

$$680{,}000 \times (3) = 2.04 \times 10^6\ mm^3$$

Total Volume Removed (100 parts):	$\boldsymbol{204 \times 10^6\ mm^3}$

Time to Manufacture

Some of the values are assumed close to the actual working conditions and total time have been found of the following processes. The total manufacturing time incorporates the material cutting time, changing of workpiece and tool, and the time taken by other alterations.

For ECM [13]**:**

- C (Specific Material Removal Rate) = $3.44\text{x}10^{-2}$ mm^3/amp.sec
- I (Current) = 2000 amp
- V (Voltage) = 20 V
- A (Frontal Area) = 80x100 = 8000 mm^2
- d (depth) = 85mm
- Efficiency = 90%
- g (gap) = 0.25 mm
- r (resistivity of electrolyte (NaCl)) = 140 Ω.mm
- T_m (Time) = 12.035 min/slot
- Total Time = 12.035x3x100 = 3610.5 min = **2.5 days**

For EDM:

- K (constant of proportionality-SI Units) = 664
- T^M (Melting point) = 660°C
- I (Current) = 25 amp
- T_m (Time) = 15.36 min/slot
- Total Time = 4608 min = **3.2 days**

For Milling/Shaper:

- f_r (Feed rate) = 200 rev/min

- d (depth of cut) = 5 mm
- T_m (Time) = 20.6 min/slot
- Total Time = **4.29 days**

For AWJM:

- Standoff distance = ¼(3.2) mm
- F_r = 500mm/sec

Manufacturing Processes Analysis

Cost Analysis

The cost of the block is 230 Rs/kg [15]. It is omitted in analysis as it is the common cost of all the processes.

Note: All the mentioned costs are in Pakistani Rupees (Rs).

1) Milling

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	4.29 days	2640.924
2.	Labor	1000	2	2000
3.	Milling cutter	600	3	1800
4.	Milling machine	450,000	1	450,000
Total	-	-	-	**456,441**

2) Shaper

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	4.29 days	2640.924
2.	Labor	1000	2	2000
3.	Shaper cutter	700	3	2100
4.	Shaper Machine	500,000	1	500,000
Total	-	-	-	**506741**

3) USM

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	3 days	1846.8
2.	Tool	1200	20	24000
3.	Labor	1000	2	2000
4.	Ultrasonic Machine	550,000	1	550,000
5.	Slurry	500	2	1000
Total	-	-	-	**578847**

4) AWJM

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	3 days	1846.8
2.	Abrasives (Silica-carbide)	3000	2	6000
3.	Labor	1000	2	2000
4.	Machine	45,000,00	1	45,000,00
Total	-	-	-	**4,509,847**

5) ECM

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	2.5 days	1539
2.	Graphite Electrode	1500	2	3000
3.	Labor	1000	2	2000
4.	Machine	300,000	1	300,000
5.	Electrolyte	500	5	2500
Total	-	-	-	**309039**

6) EDM

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	3.2 days	1969.92
2.	Electrode	1000	50	50,000
3.	Labor	1000	2	2000
4.	Machine	300,000	1	300,000
5.	Electrolyte	500	2	1000
Total	-	-	-	**354970**

7) PAC

S.No	Object	Cost of single part	Quantity	Total Cost
1.	Electricity	25.65/kWh	2.5 days	1539
2.	Labor	1000	2	2000
3.	Machine	651,000	1	651,000
4.	CO_2 Gas	26/kg	10 (45 kg)	11700
5.	Tungsten Electrode	1500/kg	10kg	15,000
Total	-	-	-	**681,239**

Environmental Analysis

The environmental impact of a manufacturing process is also dependent on the selection of the material and design of a product [3]. This is because the manufacturing of a product is directly connected to the amount of carbon emitted in consuming the electrical energy for that manufacturing process [2]. The difference in the general properties of materials such as strength, hardness and impact will have significant effect on the power consumption of the machine used to complete the product. In addition, the environmental impact can also be reduced if the proposed designs use less material. In our study, the process has been analyzed on basis of producing greenhouse gases and creating environmental pollution of any types.

Effects/Processes	Shaper	Milling	USM	AWJM	ECM	EDM	PAC	color%
CO_2 emissions								100
NOx & SOx								70
Fluid Wastes								50
Noise Pollution								30
Energy Consumption								0

The colors represent the severeness of environmental impacts of the processes from being in red the most to yellow (satisfactory) to the blue having few/zero impact.

These environmental effects have been derived by studying various industrial models. Some of these models with the data have been given below [16]:

Toxic Releases Data:

Serial	Sector	Fujitive	Stack kg	Total Air kg	Surface Water kg	U'ground Water kg	Land kg	Offiste kg	POTW Metal kg	POTW Nonmetal kg
	Total for all sectors	*0.035*	*0.131*	*0.165*	*0.056*	*0.026*	*1.01*	*0.376*	*0.001*	*0.045*
33351A	Metal cutting and forming machine tool manufacturing	0.006	0.003	0.009	0.000	0.000	0.000	0.008	0.000	0.000
331110	Iron and steel mills	0.004	0.004	0.008	0.034	0.000	0.032	0.231	0.000	0.001
331510	Ferrous metal foundries	0.003	0.003	0.006	0.000	0.000	0.011	0.035	0.000	0.000
325190	Other basic organic chemical manufacturing	0.003	0.004	0.007	0.003	0.008	0.000	0.001	0.000	0.011
325510	Paint and coating manufacturing	0.002	0.003	0.005	0.000	0.000	0.000	0.001	0.000	0.001
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.002	0.004	0.005	0.011	0.000	0.004	0.040	0.000	0.002
332430	Metal can, box, and other container manufacturing	0.001	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.000
33131A	Alumina refining and primary aluminum production	0.001	0.003	0.005	0.000	0.001	0.002	0.003	0.000	0.002
325211	Plastics material and resin manufacturing	0.001	0.002	0.003	0.000	0.001	0.000	0.000	0.000	0.002
332800	Coating, engraving, heat treating and allied activities	0.001	0.002	0.003	0.000	0.000	0.000	0.005	0.000	0.005

Greenhouse Gases Data:

	Sector	Total t CO2e	CO2 Fossil t CO2e	CO2 Process t CO2e	CH4 t CO2e	N2O t CO2e	HFC/PFCs t CO2e
	Total for all sectors	*1.09*	*0.784*	*0.218*	*0.064*	*0.008*	*0.017*
221100	Power generation and supply	0.381	0.375	0.000	0.001	0.002	0.002
331110	Iron and steel mills	0.322	0.122	0.198	0.002	0.000	0.000
33351A	Metal cutting and forming machine tool manufacturing	0.039	0.039	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.032	0.009	0.006	0.017	0.000	0.000
484000	Truck transportation	0.032	0.032	0.000	0.000	0.000	0.000
212100	Coal mining	0.024	0.003	0.000	0.021	0.000	0.000
324110	Petroleum refineries	0.016	0.016	0.000	0.000	0.000	0.000
331510	Ferrous metal foundries	0.013	0.013	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.011	0.010	0.000	0.000	0.001	0.000
481000	Air transportation	0.011	0.011	0.000	0.000	0.000	0.000

Conventional Air Pollutants Data:

	Sector	CO t	NH3 t	NOx t	PM10 t	PM2.5 t	SO2 t	VOC t
	Total for all sectors	*0.005*	*0.000*	*0.002*	*0.000*	*0.000*	*0.003*	*0.000*
331110	Iron and steel mills	0.002	0.000	0.000	0.000	0.000	0.000	0.000
484000	Truck transportation	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33329A	Other industrial machinery manufacturing	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33131A	Alumina refining and primary aluminum production	0.000	0.000	0.000	0.000	0.000	0.000	0.000
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.000	0.000	0.000	0.000	0.000	0.000	0.000
532400	Commercial and industrial machinery and equipment rental and leasing	0.000	0.000	0.000	0.000	0.000	0.000	0.000
221200	Natural gas distribution	0.000	0.000	0.000	0.000	0.000	0.000	0.000
331510	Ferrous metal foundaries	0.000	0.000	0.000	0.000	0.000	0.000	0.000
811400	Household goods repair and maintenance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
221100	Power generation and supply	0.000	0.000	0.000	0.000	0.000	0.002	0.000

Each of the processes have been simulated in the data simulation model which converts a given process to a working model to get the values as above so that the processes can be easily compared and analyzed. Hence, the results obtained have been plotted in a single table with percentage comparisons.

Comparison

Milling is an interrupted cutting operation. The hot chips fly out as the material is being removed causing safety hazard to the workers. These hot chips also release to some extent the harmful gases to the atmosphere, so if they are producing a large number of products more of this scrap is being made which contribute to the air pollution. Oiling is also used in milling, but it is recycled each time it flows so a few or zero oil is wasted in the process. In shaper machining, much more precautions are to be taken as the chip flew out distance is larger. In the rest of the processes there is no physical contact between the workpiece and the tool therefore, no heat loss due to friction is observed. So, non-traditional processes are beneficial in terms of no thermal impacts to the atmosphere. USM uses slurry to carry out the material removal which is then disposed of to the environment because fresh slurry is always required as the abrasives should remain sharp to have a good surface finish. Similar is the case of AWJM, the abrasives water is drained and cannot recycled unless filtered as it contains the particles of material removed. Other than AWJM has no environmental losses, no crushing or burning included and minimum material loss. The flowing electrolyte in ECM along with carrying off the material removed, also serves the function of removing heat and hydrogen bubbles created in the chemical reactions of the process. The removed work material is in the form of microscopic particles that must be separated from the electrolyte through centrifuge, sedimentation, or other means. The separated particles form a thick sludge whose disposal is an environmental problem associated with ECM. Large amount of electric power is required which is generated contributing to the production of more greenhouse gases. In EDM dielectric fluid is used instead of electrolyte which is fairly easy to dispose of. If graphite electrode is used, at high discharge temperatures it vaporizes and form carbon dioxide gases that pollute the atmosphere. A large amount of heat energy is dissipated to the environment in PAC as the cutting temperatures reach from 10,000 to 14,000 °C. CO_2 gas is used as the secondary gas in the vicinity of arc to help confine it and stabilize from the oncoming atmospheric air.

Energy Analysis

The energy used by each of the processes is primarily in the form of electricity and heat. Therefore, these energies have been compared of different processes.

Energy/processes	Milling	Shaper	USM	AWJM	ECM	EDM	PAC
Electricity	9.92kW	11.6kW	30.21kW	25.6kW	40kW	17.5kW	17.667kW
Heat dissipated	negligible	negligible	-	-	-	-	23.1 kJ

These processes are also simulated based on energy consumption. The model data is presented as follows:

Milling:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.036*	*0.013*	*0.011*	*0.005*	*0.001*	*0.006*
221100	Power generation and supply	0.011	0.008	0.002	0.000	0.000	0.000
331110	Iron and steel mills	0.009	0.005	0.002	0.000	0.000	0.001
33351A	Metal cutting and forming machine tool manufacturing	0.003	0.000	0.002	0.000	0.000	0.002
484000	Truck transportation	0.001	0.000	0.000	0.001	0.000	0.000
331510	Ferrous metal foundaries	0.000	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.000	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.000	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.000	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

Shaper:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.040*	*0.015*	*0.012*	*0.005*	*0.001*	*0.007*
221100	Power generation and supply	0.012	0.009	0.003	0.000	0.000	0.000
331110	Iron and steel mills	0.009	0.006	0.003	0.000	0.000	0.001
33351A	Metal cutting and forming machine tool manufacturing	0.004	0.000	0.002	0.000	0.000	0.002
484000	Truck transportation	0.001	0.000	0.000	0.001	0.000	0.000
331510	Ferrous metal foundaries	0.001	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.000	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.000	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.000	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

USM:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.046*	*0.017*	*0.014*	*0.006*	*0.002*	*0.008*
221100	Power generation and supply	0.013	0.010	0.003	0.000	0.000	0.000
331110	Iron and steel mills	0.011	0.006	0.003	0.000	0.000	0.001
33351A	Metal cutting and forming machine tool manufacturing	0.004	0.000	0.002	0.000	0.000	0.002
484000	Truck transportation	0.001	0.000	0.000	0.001	0.000	0.000
331510	Ferrous metal foundaries	0.001	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.000	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.000	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.000	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

AWJM:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.356*	*0.133*	*0.107*	*0.045*	*0.012*	*0.059*
221100	Power generation and supply	0.105	0.076	0.022	0.004	0.000	0.002
331110	Iron and steel mills	0.084	0.050	0.023	0.000	0.000	0.010
33351A	Metal cutting and forming machine tool manufacturing	0.034	0.000	0.015	0.000	0.000	0.016
484000	Truck transportation	0.010	0.000	0.000	0.010	0.000	0.000
331510	Ferrous metal foundaries	0.008	0.001	0.004	0.000	0.000	0.003
322130	Paperboard Mills	0.007	0.000	0.001	0.000	0.004	0.000
324110	Petroleum refineries	0.006	0.000	0.002	0.004	0.000	0.000
325190	Other basic organic chemical manufacturing	0.006	0.000	0.002	0.000	0.002	0.000
211000	Oil and gas extraction	0.004	0.000	0.004	0.000	0.000	0.000
481000	Air transportation	0.004	0.000	0.000	0.004	0.000	0.000

ECM:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.024*	*0.009*	*0.007*	*0.003*	*0.000*	*0.004*
221100	Power generation and supply	0.007	0.005	0.002	0.000	0.000	0.000
331110	Iron and steel mills	0.006	0.003	0.002	0.000	0.000	0.000
33351A	Metal cutting and forming machine tool manufacturing	0.002	0.000	0.001	0.000	0.000	0.001
484000	Truck transportation	0.000	0.000	0.000	0.000	0.000	0.000
331510	Ferrous metal foundaries	0.000	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.000	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.000	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.000	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

EDM:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.028*	*0.011*	*0.008*	*0.004*	*0.001*	*0.005*
221100	Power generation and supply	0.008	0.006	0.002	0.000	0.000	0.000
331110	Iron and steel mills	0.007	0.004	0.002	0.000	0.000	0.000
33351A	Metal cutting and forming machine tool manufacturing	0.003	0.000	0.001	0.000	0.000	0.001
484000	Truck transportation	0.000	0.000	0.000	0.000	0.000	0.000
331510	Ferrous metal foundaries	0.000	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.000	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.000	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.000	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

PAC:

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*0.054*	*0.020*	*0.016*	*0.007*	*0.002*	*0.009*
221100	Power generation and supply	0.016	0.011	0.003	0.000	0.000	0.000
331110	Iron and steel mills	0.013	0.008	0.003	0.000	0.000	0.002
33351A	Metal cutting and forming machine tool manufacturing	0.005	0.000	0.002	0.000	0.000	0.002
484000	Truck transportation	0.001	0.000	0.000	0.001	0.000	0.000
331510	Ferrous metal foundaries	0.001	0.000	0.000	0.000	0.000	0.000
322130	Paperboard Mills	0.001	0.000	0.000	0.000	0.000	0.000
324110	Petroleum refineries	0.001	0.000	0.000	0.000	0.000	0.000
325190	Other basic organic chemical manufacturing	0.001	0.000	0.000	0.000	0.000	0.000
211000	Oil and gas extraction	0.000	0.000	0.000	0.000	0.000	0.000
481000	Air transportation	0.000	0.000	0.000	0.000	0.000	0.000

Comparison

The milling and shaper are slow processes as compared to the rest of non-traditional processes because of lower material removal rates. Therefore, they consume more electric energy and hence are less efficient. From the non-traditional processes, ECM requires a large amount of electric input as the discharge current is high while in EDM the tool wear is continuous, so the time required to change the tool makes the process more costly and hence more energy is required. PAC produces a large amount of heat energy being dissipated in the environment. Therefore, the energy losses in PAC are very high.

Accuracy Analysis

The accuracy of any process can be compared based on various factors as tool wear, surface finish, roughness, time to manufacture etc. The main aspect of accuracy is compared on the basis of surface roughness. Surface roughness refers to the height of macro and micro asperities and irregularities present on a finished surface after machining; while surface finish indicates quality of that surface using various attributes (like fine, rough, good, poor, etc.). Surface roughness can be measured and expressed quantitatively that is why it is being used for quantitative accuracy analysis.

Tool Wear

Manufacturing process	Tool Wear
Milling	Intermediate
Shaper	Intermediate
USM	High (approx. 1:1)
AWJM	Intermediate (due to spattering)
ECM	Low (No wear)
EDM	High (1:1 to 1:100)
PAC	Intermediate (Vaporization due to high Temp:)

Surface Roughness

The standard of machined surface roughness (Ra) is 3.2 µm. Surface finish requirements can be increased to 1.6, 0.8 and 0.4 µm according to the process and material being machined. Ra is calculated as the Roughness Average of surfaces measured using microscopic peaks and valleys.

- The machining accuracy of milling is generally up to IT8 to IT7 (ISO System of limits and fits), and the surface roughness is 6.3-1.6µm.
- On shaper the roughness reaches to about 16 µm [11].
- The surface roughness (Ra) for Aluminum using USM is found to be 1.5 to 2 µm [5].

- Surface roughness in EDM depend both on material properties and electrode being used. The surface roughness value, using graphite electrode and in the range of discharge currents as 22-25 amp, will lie in the range from 0.8 to 6 µm [14] [8].
- The surface roughness of ECM varies from as low as 0.2 µm to as high as 5.87 µm as the voltage changes continuously during the operation [6] [7].
- In the PAC, various parameters effect the surface finish as current density, type of gas, velocity, voltage, size of nozzle etc. The typical surface roughness values are higher in this process ranging from 15 to 42 µm [9]. Although, if the process is made more efficient by taking out the operation in controlled environments the Ra value can be minimized to about 15 µm.
- The surface roughness values for AWJM ranges from 5 to 7 µm [10].

Hence, it can be deduced from the data above that the minimum surface roughness values are for the EDM and ECM processes while PAC has the lowest surface finish and refining is required for final design.

The Efficient Manufacturing Process

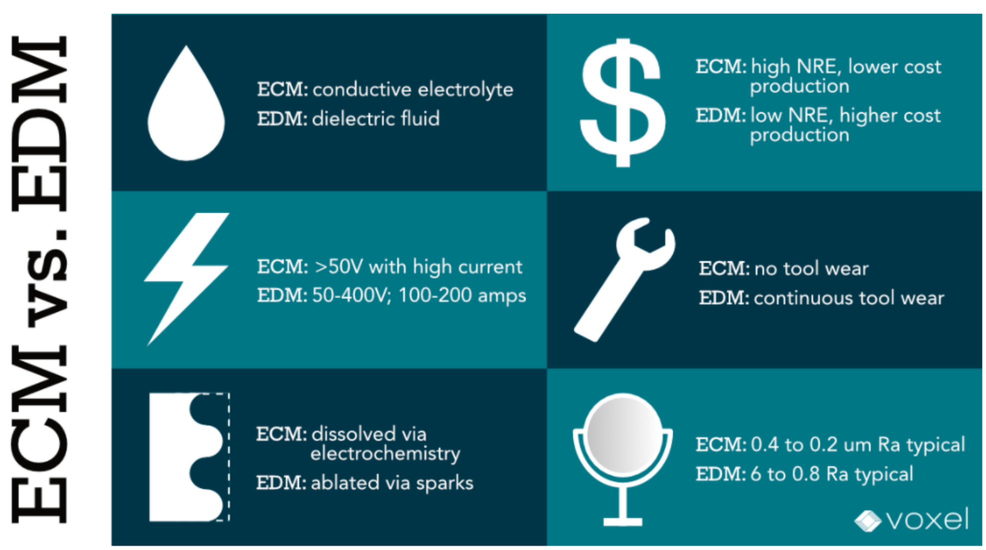
Hence, keeping in view the above analysis and comparing all the feasible processes that can be used to manufacture the desired component represent the following results.

In the cost analysis sector, the traditional processes are somewhat less expensive and easily available as the machines are readily accessible in the market. Comparing the non-traditional processes AWJM is the most expensive as the cost of single machine is very high. ECM uses a large amount of electricity while the initial cost of EDM is lower but the continuously changing of electrode requires both more time and cost. PAC is cost effective but additional surface finishing process is required.

In the environmental sector, PAC produces a large amount of harmful gases while ECM uses electricity which is generated using processes that produce many harmful gases. Therefore, they both mainly contribute to the environmental hazards. Also, the slurry in ECM is difficult to dispose of and is hazardous to environment.

Energy sector results in the high heat energy being dissipated in PAC and use of large amount of electric energy in ECM. Other processes do not contribute much to the loss or generation of energy.

Accuracy has been caried out the observing the finalized product compared with the actual dimensional design including the surface finish. The main factors that affect the accuracy have been tool wear and surface roughness which has been found to be minimum in both EDM and ECM while the highest in PAC [14].



On account of the above-mentioned analysis, keeping in view mostly the environmental effects and emphasizing the part accuracy, **Electric Discharge Machining** have been preferred for the manufacturing of given component.

Advantages and Disadvantages of the Selected Process

Advantages of EDM include:

- Ability to machine complex shapes that would otherwise be difficult to produce with conventional cutting tools [12].
- Machining of extremely hard material to very close tolerances.
- Very small work pieces can be machined where conventional cutting tools may damage the part from excess cutting tool pressure.
- There is no direct contact between tool and work piece. Therefore, delicate sections and weak materials can be machined without perceivable distortion.
- A good surface finish can be obtained; a very good surface may be obtained by redundant finishing paths [8].
- Very fine holes can be attained.
- Tapered holes may be produced.
- Pipe or container internal contours and internal corners down to R 0.001".

Disadvantages of EDM include:

- Difficulty finding expert machinists.
- The slow rate of material removal.
- The additional time and cost used for creating electrodes for ram/sinker EDM.
- Reproducing sharp corners on the workpiece is difficult due to electrode wear.
- Specific power consumption is very high.
- Power consumption is high.
- "Overcut" is formed.
- Excessive tool wear occurs during machining.
- Electrically non-conductive materials can be machined only with specific set-up of the process.

Conclusion

To sum up, various analysis has been taken out using different techniques and help taken from the data available in vast collection of literatures. **Electric Discharge Machining** have been selected as the most suitable process for the manufacturing of desired component. EDM is a non-traditional process and does not include physical contact of tool and workpiece. With intermediate cost of machine, electrodes, and labor, it is not an expensive process as compared to the high surface finish values and part accuracy it gives. The fluid being the dielectric is not hazardous to environment and can be easily recycled. Hence, it is an environmentally friendly process of manufacturing. The energy consumption of the process is about 43.75% lower than many of the non-traditional processes. The hardness and strength of the work material are not factors in EDM, because the process is not a contest of hardness between tool and work. Applications of electric discharge machining include both tool fabrication and parts production. The EDM process is most widely used by the mold-making, tool, and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low (less than 500 parts).

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