Reverse Engineering of Yamaha CY80 Clutch Basket using 7075 Aluminum Alloy for Component Functional Requirement

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Abstract
The CY 80 clutch basket is a bowl-shaped gear- driven housing bolted onto the end of the clutch shaft and functions as the cover for clutch components assembly. The functional requirement of this part requires high strength and wear resistance characteristics. This research work focuses on the design and development of permanent mould for the production of CY 80 clutch basket using 7075 Aluminum alloy. The CY 80 clutch basket was designed using Creo Element software and manufactured by gravitational casting process using a crucible furnace. Virtual simulation of the produced component shows that the design is safe. Material analysis and further test performed by running Cy80 motorcycle engine that is coupled with the clutch basket shows that the manufactured CY 80 clutch basket performs its intended function.

1. Introduction

A clutch is that part of engine which engages or disengages power from the engine crankshaft to transmission. A clutch is mechanism by which you change the gears. In simple words, it turns on or off power to rear wheel. The function of the clutch is the summation of the functions of parts in the clutch system and these parts includes clutch plate, Clutch basket, Clutch hub, pressure plates, Clutch springs, clutch catcher, clutch balls, lever, clutch cable etc. (Naga and Tippa, 2013).

A clutch is a mechanical device that engages and disengages the power transmission, especially from driving shaft to driven shaft. Motorcycles typically employ a wet clutch with the clutch riding in the same oil as the transmission. These clutches are usually made up of a stack of alternating plain steel and friction plates. Some plates have lugs on their inner diameters that lock them to the engine crankshaft. Other plates have lugs on their outer diameters that lock them to a basket that turns the transmission input shaft. A set of coil springs or a diaphragm spring plate force the plates together when the clutch is engaged (Wikipedia, 2014).

Depending on the orientation, speeds, material, torque produced and finally the use of the whole device, different kinds of clutches are used. The clutch in itself is a mechanism, which employs different configurations and different principles in various models available. In the following lines, we have provided the different kinds of clutches that are available to include:

i. Friction Clutch
ii. Dog Clutch
iii. Cone Cutch
iv. Overrunning Clutch
v. Safety Clutch
vi. Centrifugal clutch
vii. Hydraulic Clutch
viii. Electromagnetic Clutch

However, the motorcycle clutches can further be categorized into two depending on working medium. They are:

- **Wet clutch -** is called wet because it is actually wet with engine oil. The engine oil provides cooling as well as lubrication between the clutch cage and mating parts. Generally, a wet clutch will have a longer life and will take more abuse from the rider.
- **Dry clutch** - does not live in an oil bath, and is simply dry.

Unless you are a professional motorcycle mechanic, you normally cannot see whether a motorcycle has a wet or dry clutch just by looking at the bike. The wet clutch generally lives longer and therefore more people go for it.

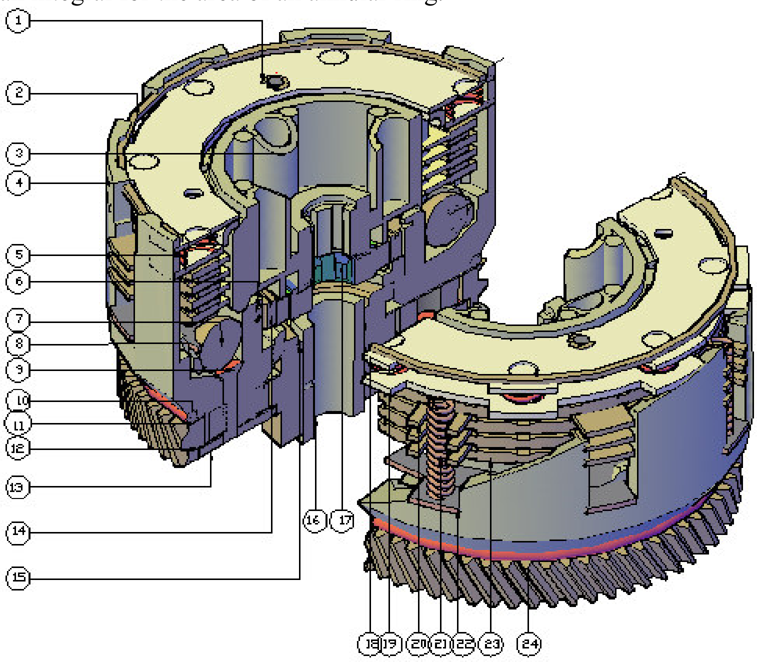
2. The CY80 Clutch System.

In a CY80 motorcycle, there are about 25 different parts that work together in an assembly to function as the clutch. Fig 1 shows Yamaha CY80 motorcycle and the complete assembly of the CY80 motorcycle clutch. These parts are inserted or are being housed by the clutch basket shown in Figs 2 and 3

Fig 1 Yamaha CY80 motorcycle and the complete assembly of the clutch

2.1 Design and Manufacture of CY80 Clutch Basket

Once the power leaves the engine's crank or flywheel (if present), the first component in the system is typically the clutch. Clutch design is a complex area, but the principles remain largely the same throughout motorsport. Nearly all motorsport clutches are of the friction type, consisting of (usually) between one and four friction plates, a pressure plate and some form of spring to provide an axial force that presses the plates together in order to transmit engine torque. The performance of a clutch is usually defined as its torque capacity, which is the level of torque it can transmit before slipping occurs. This is a function of the friction material used (specifically its coefficient of friction), the contact area available and the axial force available to keep the plates in contact. The friction available is a function of the materials' coefficient of friction multiplied by the spring force, derived via an integral for the area of an annular ring.



24	CLUTCH SPROCKET	1
23	FIBRE	5
22	LOWER SPRING PLATE	
21	LOWER SPRING	4
20	FIBRE PLATE	5
19	LOWER TP PLATE	1
18	UPPER TP PLATE	1
17	CATCHER	1
16	CLUTCH BUSHING	1
15	BRASS BUSHING	1
14	CATCHER HOUSING	1
13	CLUTCH BOTTOM PLATE	1
12	LOWER GASKET	1
11	UPPER GASKET	1
10	"O" SEAL	1
9	REVETTNG PIN	3
8	BALL SEATING	1
7	BALL BEARING	16
6	CATCHER PIN	1
5	UPPER SPRING	4
4	CLUTCH BASKET	1
3	CLUTCH MOON	1
2	MAIN PIN	1
1	TOP PLATE PIN	2
ITEM	DESCRIPTION	QTY

Fig 2 Complete sliced assembly of the CY80 motorcycle clutch

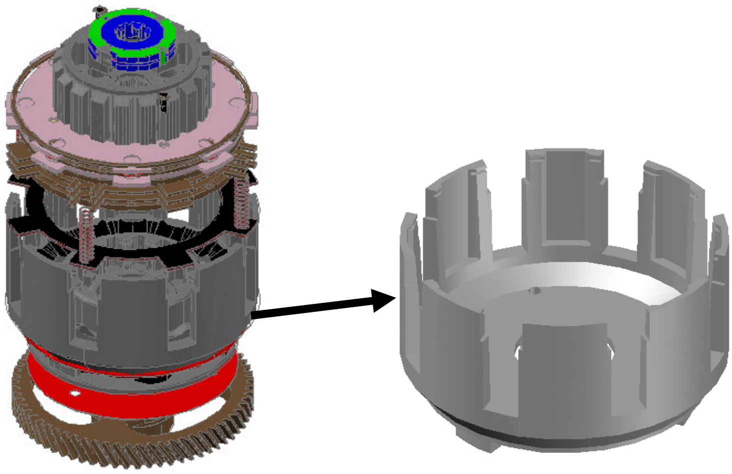


Fig 3: a) Exploded view of clutch b) clutch basket

The equation below provides the torque capacity of a singular disc surface (one side), which can then simply be multiplied by the number of friction surfaces involved to determine the total torque capacity for a clutch design (David, n. d).

$$T = \frac{F\mu\left(D^3 \; ? \; d^3\right)N}{3(D^2 \; ? \; d^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where T = Torque capacity, (4.5Nm from table 2); F = function of spring force; μ = coefficient of friction, (0.50 from table 3); D = disc outer diameter (106mm from Fig 4); d = inner diameter (86 from Fig 4); and N = number of friction surfaces (5*2 =10)

The force that is transmitted to the clutch can be calculated using equation 1 and the torque generated is contain in the Yamaha CY80 motorcycle general specification table (table 1). Table 2 shows Friction coefficient and maximum working temperature for clutch fibre materials.

The CY 80 clutch basket is a bowl-shaped gear-driven housing bolted onto the end of the clutch shaft and functions as the cover for clutch components assembly. The functional requirements of this component are high strength, wear resistance and dimensional clearances.

From equation 1:

$$F = \frac{3T(D^2 - d^2)}{\mu(D^3 - d^3)} = \frac{3\times 45(0.106^3 - 0.86^3)}{0.23(0.106^2 - 0.86^2)}$$

= 511.61N

Table 1: Yamaha CY80 Motorcycle Specifications

Specification	**Value**
Dimension(mm) (L*W*H)	1860×660×1050
Engine Type	Single-cylinder,air-cooled,4-stroke
Displacement(ml)	68
Power(kw/r/min)	3.7KW/6500r/min
Maximum Torque(N.m./r/min)	4.5N.m/5500r/min
Starting	Electric/kick
Max.speed(km/h)	≥70
Brake Type(Front/Rear)	Drum/Drum
Tyre size(Front / Rear)	F:2.25－17 R:2.50－17
Ignition mode	CDI
Wheel base(mm)	1210
Battery	12V 4 AH
Net weight(kgs)	92
Max Loading (kgs)	150
Wheel	ALLOY WHEEL
40' GP	
40' HQ	126
Warranty Period	6000KM /12 Months

Table 2: Friction materials for clutch fibre

Material combination	Coefficient of friction (μ)	Temp.(Max) ^{0}C
LO31/Aluminum	0.23	150
SFBU/Aluminum	0.50	325

Source: Ganesh, Anil and Bhaskar P (2003).

Fig 4 Yamaha CY80 Clutch fibre

A Computer Aided Design (CAD) approach was used and the modelling and simulation were done with the use of AutoCAD and Creo Element/Pro 5.0 softwares respectively. Figs 2 and 3 were drawn with AutoCAD.

2.2 Static Analysis of Clutch Basket using Creo Element/Pro 5.0

Computer Aided Stress Analysis (CASA) that was performed to check the structural integrity of the clutch basket. Finite Element method was used to simulate the real life condition of the clutch basket using Pro-mechanica. The material properties were assigned and the properties fed include the young modulus, poisons ratio, the yield strength and density of the Aluminum alloy. Component constraints were carefully defined in appropriate areas and load condition added. Tetrahedral Meshing type was applied and Multi-Pass Adaptive convergence method with polynomial order of 7 and percentage convergence limit of 10% was used. The analysis was also designed to converge on local displacement, global strain energy and global RMS stress (Aduloju et al, 2014).

Graph in Fig 5 shows the virtual model of the clutch basket and the stress variation across the component with maximum value of 55N/mm^2. Fig 7 shows the clutch basket has maximum displacement of 0.095mm.The convergence of the critical measures (local displacement and Strain energy) occurs at a polynomial order of 5 which is below the set limit of 7 is shown in Figs 6-8. The convergence of the measures occurs below the set limit of 10% and these ascertain that the results are accurate.

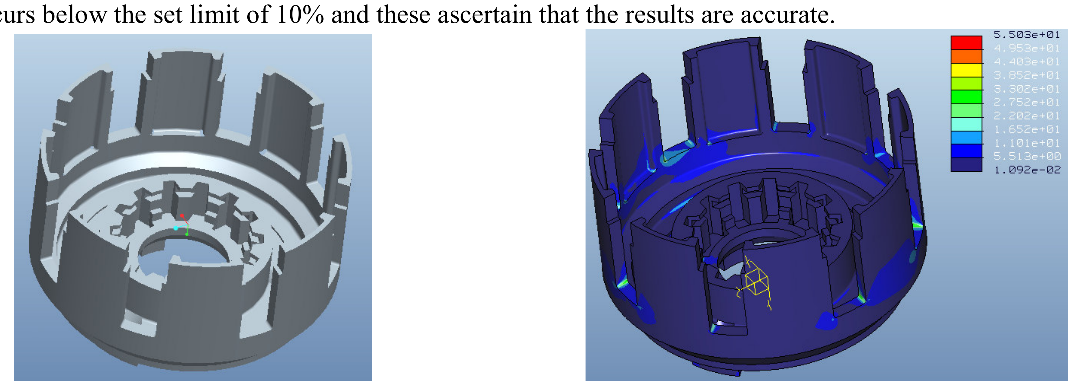


Fig 5: a) Virtual Model for Clutch basket b) Stress Analysis of the clutch basket

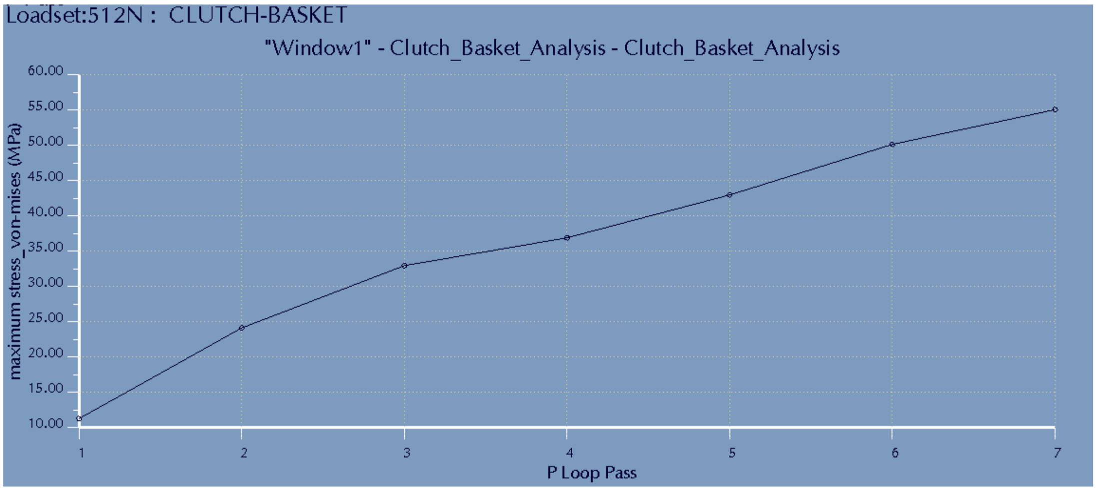


Fig 6: The plot of Stress against the Polynomial loop pass

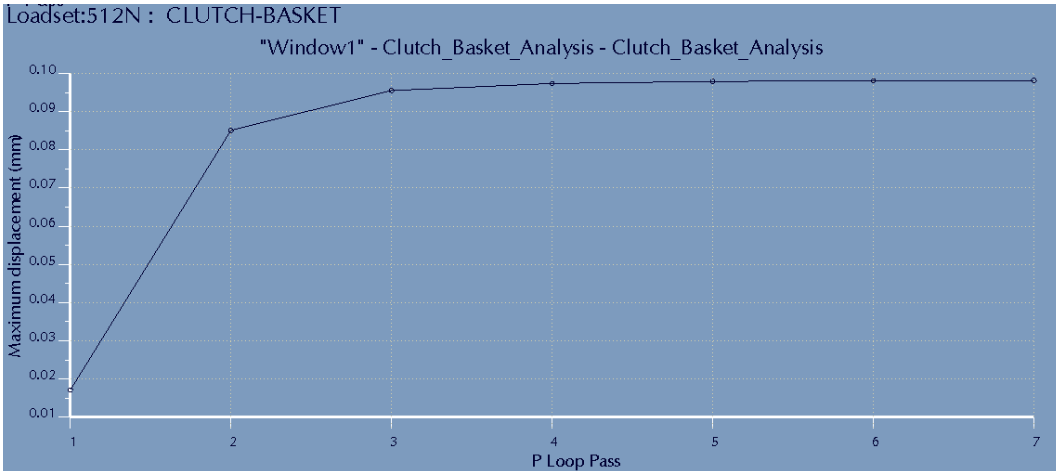


Fig 7: The plot of maximum displacement against the Polynomial loop pass

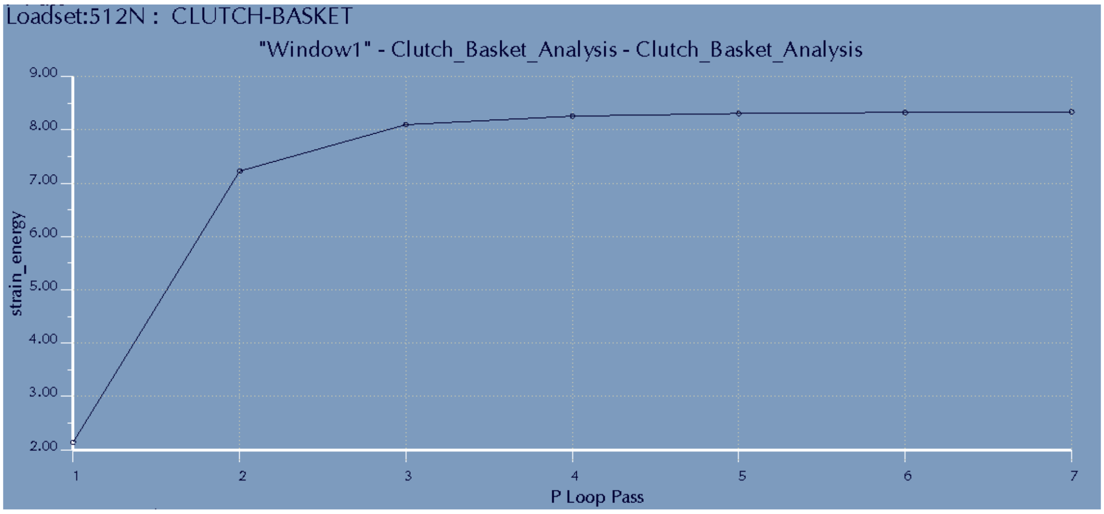


Fig 8: The plot of Strain Energy against the Polynomial loop pass

2.3 The Material used for Yamaha CY80 Clutch Basket

Clutch baskets are typically manufactured from a machined aluminum alloy, which is then hard anodised for wear performance. Engagement of the basket with the friction discs is achieved by slotting the friction discs to accept the legs of the basket as shown in Fig 5 7075 Aluminum alloy was used and the chemical composition and mechanical properties of the grade of aluminum is shown in table 3.

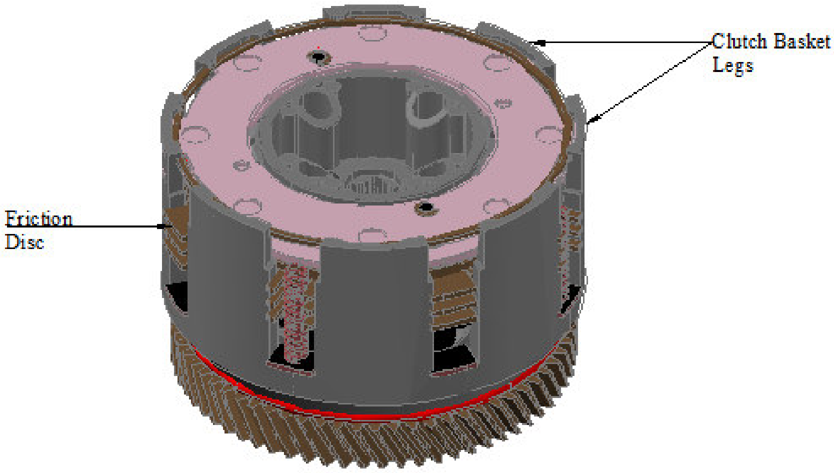


Fig 9: CY80 Clutch assembly

Table 3: Chemical Composition Limits (WT. %)

Alloy	Al	Zn	Mg	Cu	Mn	Fe	Si	Cr	Ti	Total
Values	86.67	5.60	2.50	1.60	0.30	0.50	0.40	0.23	0.20	100.0

The choice of 7075 aluminum alloy is due to its strength and hardness qualities. Alloy 7075 products have application throughout aircraft and aerospace structures where a combination of high strength with moderate toughness and corrosion resistance are required (ALCOA, n. d.). This group of alloys exhibits the highest strength as far as aluminum is concerned and in many cases they are superior to that of high tensile steels. It is also heat treatable cause of the presence of zinc and magnesium in the alloy and this gives rise to their very high strength and hardness (Ron and Alcan, 1994).

2.4 The Manufacture of Clutch Basket.

The production was of two stages:

- Production of permanent mould
- Testing of the mould (production of clutch basket)

In these stages, the general manufacturing processes used are casting, fettling and machining.

The first stage which is the production of permanent mould through sand casting can be broken down into pattern making, sand mould production, melting and pouring, fettling and machining to specification. The pattern was formed by adding necessary allowances to an existing CY 80 motorcycle clutch basket. The table 1 below shows the necessary allowances used for the clutch basket pattern. The type of furnace used to melt the aluminum alloy is crucible furnace.

In the second stage, manufacturing processes used are casting, fettling, machining, heat treatment, surface finishing and packaging. Fig 9 shows the production system layout of clutch basket. The permanent mould is made of brass. Fig 10 shows the permanent mould for the clutch basket. It was designed using AutoCAD software.

To ensure that the casting gives a good quality product the following precautions were taken:

- The crucible was first preheated to remove any moisture from the furnace and crucible.
- The gas was turned half on in order to avoid rapid heating.
- The aluminum ingots to be used were placed on top of the furnace so that the temperature could be relatively raised.
- Aluminum ingots were then placed into the crucible with steel tongs.
- All steel tools such as tongs are pre-warmed. The gas pressure is turned up to full.
- As the aluminum begins to melt a small amount of ‘flux’ was sprinkled over the aluminum to prevent oxidisation of the molten aluminum.
- When the aluminum has melted fully and is approximately 700^0C the gas is turned off and a degassing tablet is added. This removes any impurities, in the form of gas.
- The Aluminum was poured at temperature of 650^0C and the dross was removed.
- During pouring into the mould, the flow of aluminum is kept constant.

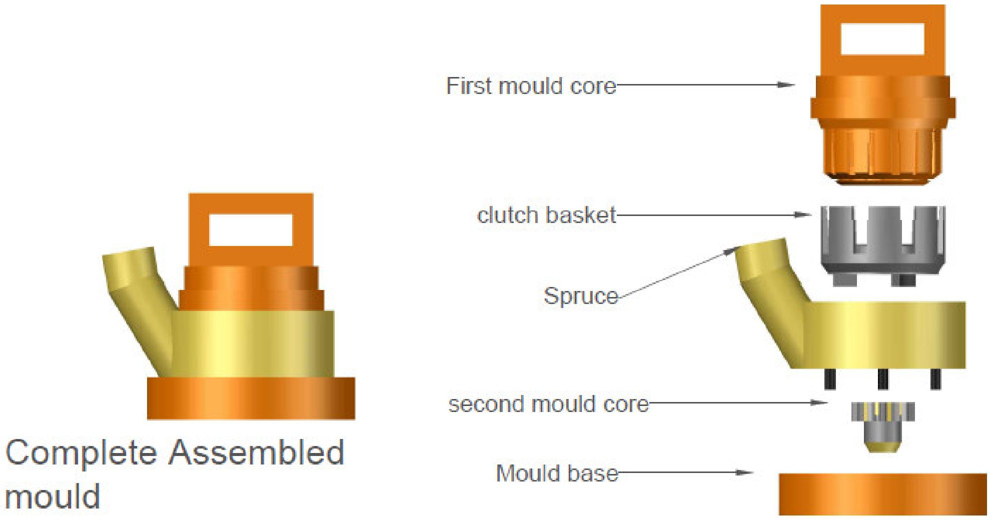


Fig 10: Clutch basket permanent mould designed with AutoCAD

Fig 11: Clutch basket permanent mould produced through sand casting.

Fig 12 shows the relationship between the mould and clutch basket while Fig 13 shows the packaging of the clutch basket

a Cast product (Clutch basket)

b

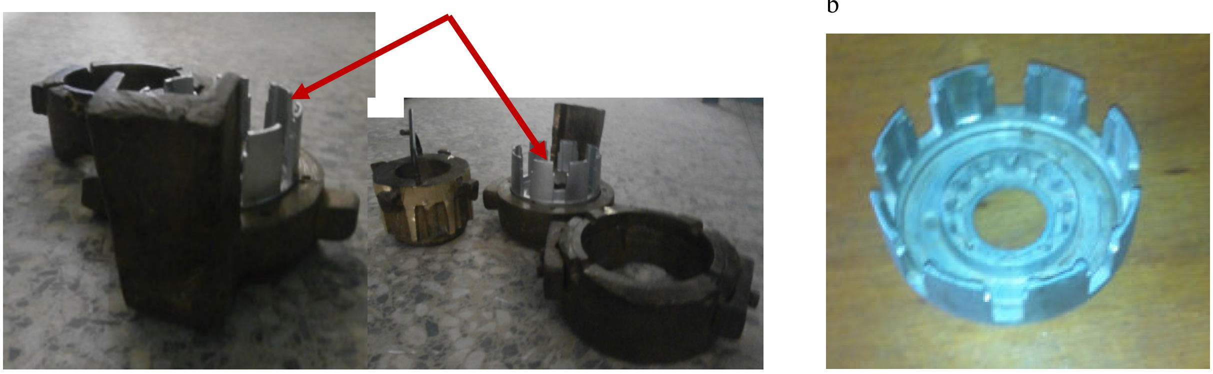


Fig 12: a) Cast product (Clutch basket) in the mould b) Clutch basket for CY80 Motorcycle

Fig 13: Packaged Clutch basket

Table 4: The allowances used for the clutch basket pattern.

Type of Casting Allowances	Value	Unit
Shrinkage	1.0	mm
Machining	1.5	mm
Draft	1.0	mm
Finishing	1.0	mm

3. Material Testing and Analysis

3.1 Material preparation

Material samples were obtained from the 7075 Aluminum Alloy melt for Clutch basket and produced by casting round cylindrical rods of 20 mm diameter and 500 mm long. Some of the cast rods were rapidly cooled to room temperature by knocking them out 5 minutes after castings while the others were cooled gradually inside the mould to room temperature. Round tensile samples and impact test samples were machined from these categories of rods according to British Standard BSEN 10002-1:1990 and ASTM Standard E 602-91 respectively (BSEN, 1990 and ASTM, 1992). The tensile test samples have a gauge length of 30 mm and diameter of 5 mm. The impact test samples were V notched to a depth of 2 mm. Samples were also sectioned from cast rods for metallographic and hardness tests.

3.2 Heat Treatment

Precipitation hardening was carried out on sample machined from castings that were gradually cooled. Precipitation hardening was carried out by first solution treated another set of machined, metallographic and hardness test piece samples at a temperature of 465 °C for 2 hours followed by rapid quenching in cold water. These quenched samples were then subjected to a precipitation hardening treatment (age hardening) by heating them to 120 °C, holding them at this temperature for 5 hours and then followed by air cooling to room temperature.

3.3 Tensile testing

Tensile testing of all these specimens was conducted per British Standard BSEN 10002-1:1990. Three samples were tested from each heat-treated condition and as cast samples. The tests were carried out at room temperature with a crosshead speed of 1 mm/min using a computerised Instron 3369 electromechanical testing machine. Load – displacement plots were obtained on an X-Y recorder and ultimate tensile strength and percentage elongation values were calculated from this load – displacement diagrams. The average values from three test samples for heat-treated and as cast samples are 572Mpa and 512Mpa and elongation at break of 12% and 15% respectively.

3.4 Impact Testing

Impact testing of all these specimens was conducted per ASTM Standard E 602-91. Three samples were tested from each heat-treated condition and as cast samples. The tests were carried out using Izod impact test method on Houndsfield balance impact-testing machine. The amount of impact energy absorbed by the specimen before yielding was read off on the calibrated scale attached to the machine as a measure of impact strength in Joules. The average values from three test samples are 9.4J for as-cast samples and 14.2J for heat treated sample.

3.5 Hardness Test

The control and the heat treated samples were subjected to the Brinell hardness test using the Houndsfield extensometer in compression mode. The specimens were polished to 600 microns and mounted on the machine using a dwell time of 15 seconds. The diameter of the impression left by the ball was then measured using the

Brinell calibrated hand lens and the corresponding Brinell hardness number was determined. The brinell hardness for heat-treated and as cast samples are 202HB and 173HB.

3.5 Wear or Abrasion Test

The wear resistance was determined for all materials using a pin-on disc test in air under dry sliding conditions and at room temperature, with an applied load of 5.0 N, giving a nominal contact pressure of 0.5 MPa and a disc velocity of 0.14 ms^{-1}. The pin, which had a diameter of 5 mm _t 0.1 mm, was machined after the T6 heat treatment using a cooled lubricant and slow machining speeds to avoid influencing the microstructure. The wear resistance was recorded as 96µm and 98µm for as-cast and heat treated samples.

The durability of the clutch basket is dependent on its ability to meet required mechanical properties. Tensile Strength, Wear resistance and Hardness of the clutch basket must conform to standards (Talon n. d.; ASM, 1990; Jothi, Venkateswarlu,and Jainshe, 2009). Table 2 shows the mechanical properties of Clutch Basket as compared to its functional requirement. The results obtained from our analysis sat the clutch basket will perform its intended function. There was ±2Mpa deviation for tensile strength and ±4 µm for wear resistance.

Table 2: Mechanical Properties of Clutch Basket as Compared to its Functional Requirement.

	As-cast	Heat treated	Functional Requirement	Unit
Tensile Strength	572	512	570	MPa
Hardness	153	139	150	HB
Wear resistance	96	98	100	µm
Impact	9.4	14.2	10	J

3.6 Optical metallography

The sample was taken through the process of metallography: sample selection, mounting, grinding, polishing and etching. The morphology of the microstructures were then characterized by optical microscopy after etching with sodium hydroxide.

Fig 14 shows the microstructure of the as-cast with the magnification of 250µm. The microstructure of 7075 Al alloy shows $MgZn_2$ phase in Al matrix. Grain coarsening leads to an increase in the grain boundary area which increases the amount of energy required for the movement of dislocations required to cause fracture (Liao, Zhaoand Zhu, 2004; Zheng et al, 2009; Kumar, Nicola, and Van, 2009). Thus, the material can withstand a higher plastic deformation before the final fracture. However, the percentage elongation of as-cast is very small because of embrittlement of 7075 Al alloy as a result of microsegregation of $MgZn_2$.

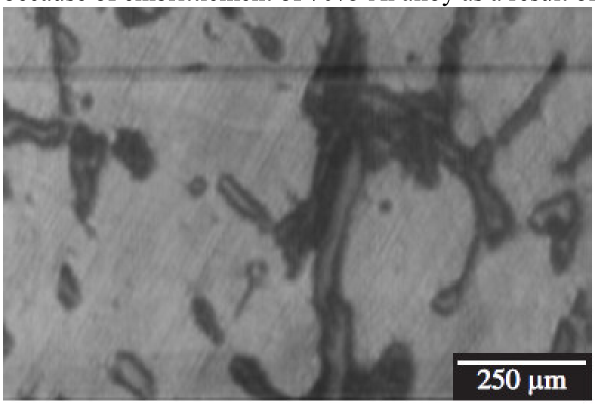


Fig 14: The microstructure of the as-cast 250µm

3.7 Clutch Basket Coupling and Testing of Clutch Basket in a Moving Motorcycle

The clutch basket produced has been tested on a Cy80 Motorcycle. The motorcycle was ridden for 5 hours. It was observed that there were no problems in coupling of the clutch basket and the clutch did not fail. The edges of the clutch were checked for wear and there was no noticeable wear.

4. Conclusion

The values obtained from the Material analysis have been observed to be close to the mechanical properties required for the functional requirement of Clutch Basket. The clutch basket produced using Aluminum 7075 possesses the required tensile strength, hardness, wear resistance and impact resistance. It will perform its intended function. The material testing and has helped to validate the CASA results.

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