Investigation of Mechanical Properties of Brass Francis Turbine Manufactured by Local Investment Casting Technique in Nepal

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Abstract. Most of the hydro turbines in Nepalese power plants are imported from foreign industries. Findings from the studies have shown that up to 60% of the 13,000 MW capacity hydropower projects under the survey stage in Nepal would need Francis type of turbine with unit size below 5 MW. To meet the demand for turbines, Nepal has imported turbines worth US$ 5,616,072. The imported turbines from foreign industries could not address local problems of Nepalese hydropower. In Nepal, due to the sediment-laden condition of rivers alternative design and manufacturing techniques of turbines are necessary. To provide the new manufacturing techniques of Francis turbine in Nepal local casting process can be a solution because metal casting is a hereditary profession in Nepal since ancient periods till now. Large-sized bronze cast bells that are placed in Nepalese temples were manufactured in ancient times without a proper theoretical study on them. This paper discusses the materials testing of investment cast and sand cast brass materials of 14 kW Francis runner of Turbine Testing Lab (TTL) for exploring the possibilities of manufacturing Francis turbine. Tensile, Compressive and Charpy impact tests were performed base on ASTM standards and also the microscopic study was conducted at Kathmandu university laboratory. These testing results can be helpful for further studies on alternate turbine manufacturing processes as well.

Keywords: Francis Turbine, Hydropower, Brass, Investment Casting, Material Testing

1. Introduction

Nepal is among the richest country in water resources, with one of the highest per capita hydropower potentials in the world. The estimated power potential in Nepal is about 83,000 MW and total economically feasible hydropower potential is about 42,000 MW, out of which only less than 700 MW has been harnessed to date [1]. The demand for electrical energy in Nepal will reach 3,600 MW by the year 2027 [2]. Preliminary findings from the current studies have shown that up to 60% of projects under the survey stage in Nepal with a total capacity of more than 13,000 MW would need Francis type of turbine with unit size below 5 MW [2]. Sediment induced high turbine wear problem in the hydraulic machinery is one of the major problems in the operations and management of the hydroelectric projects in sediment-laden rivers. Excessive turbine wear causes turbine operational problems with a unit outage, drop-in turbine efficiency, generation loss, and eventually loss in revenue [3]. Besides, it faces an
inevitable problem of maintenance and operation due to sediment erosion in the run-off-river power plants [1].

With the increase in independent power producers and local manufacturers, there is an increasing demand for turbine quality, performance and reliability. It is realized that competences to exploit water resources for hydropower not only depend on financing, design and management of projects, but also knowledge generation and local adaptability of technology. Although Nepalese companies are capable of designing, manufacturing and installing micro hydro systems, the lack of performance data about the manufactured turbines is undermining the confidence in local products. Due to that reason, turbines or the design of the turbines are usually imported, which do not take into account the local problems such as erosion [4]. To meet the demand for turbines, Nepal has imported US$ 5,616,072 worth of turbines [5]. One approach to design and manufacture turbines suitable for the sediment-laden run of river is to develop local manufacturing capabilities of erosion friendly. Francis turbine design has successfully practiced in TTL.

Figure 1. 14 kW of Francis Turbine after Machining at TTL [6].

Metal casting for bells on the ancient technique of manufacturing frequently used to cast sculptures. Metal casting is a hereditary profession in Nepal used to cast brass and bronze equipment without properly understanding engineering aspects. With the modern advancement and understanding of the casting process, the conventional casting facilities and techniques could be used to develop turbine manufacturing capabilities in Nepal. Brass and bronze being commonly used materials, one of these materials could be a starting point to study metal casting process to manufacture Francis turbine locally in Nepal. One example of brass material used as Francis turbine runner could be seen in Fewa hydropower station having installed capacity of 1 MW. With these motivations, the mechanical properties testing of investment and sand-cast brass materials of 14 kW Francis runner of TTL have been done at Kathmandu University Laboratory to provide the testing data that can also be useful for further studies on alternate turbine manufacturing process.

2. Methodology

TTL has manufactured 14 kW Francis runner in brass using traditional investment casting techniques. The temperature of mold baking was up to 500 degrees centigrade and the duration of mold baking was up to 24 hours [6]. The investment cast materials which were from the runner and riser part of the 14 kW cast Francis turbine of Turbine Testing Lab (TTL) were selected for making testing specimens. Due to the limitation of materials for specimens to perform all tests, the chips originated while machining investment cast materials were collected and again these materials were sand cast to make testing specimens at the same condition as investment casting technique. The experiments consisted of the preparation of the testing standards, equipment and procedures of testing. Charpy impact test of both sand cast and investment cast brass, compression test of investment cast brass, the tensile test of sand-cast brass and microscopic study of both investment and sand-cast brass were performed consequently at Kathmandu university laboratory.
2.1. Charpy Impact Test
Considering ASTM Standard E23 [7] for the Charpy impact test, the impact test specimen was designed as shown in figure 2. All dimensions are given in mm.

![Figure 2. Charpy impact test specimen.](image)

The impact test specimens were machined from cylindrical runner and riser of investment cast 14 kW Francis turbine made of brass material. The V-notch of impact test specimens were carefully cut by using a hacksaw. Impact tests were performed on the Charpy impact test having 300 J maximum energy considering ASTM standard E23. The impact test was repeated 6 specimens at identical conditions. During the test energy absorbed by the specimen to failure was measured to estimate impact energy.

2.2. Compression Test
Considering ASTM [8] for the compression test, the compression test specimen was designed as shown in figure 3. All dimensions are given in mm.

![Figure 3. Compression test specimen.](image)

The compression test specimens were machined in the required dimensions. Compression tests were performed on the compression testing machine ENKAY DIGIMAX-109 model having a maximum capacity of providing 100 kN of a load. The compression test was repeated on 4 specimens at identical conditions. During the test maximum load absorbed by the specimen to failure was measured to estimate compressive strength.

2.3. Tensile Test
Being runner and riser part of investment cast Francis turbine cylindrical, first referring to ASTM [9] standard cylindrical specimen design was chosen but due to breaking of a specimen while turning in lathe rectangular specimen design was chosen as the standard tensile test specimen. The rectangular tensile test specimen used in this work is shown in figure 4. All dimensions are given in mm.
The tensile test specimens were machined in the required dimensions. Tensile tests were performed on the Universal Testing Machine (UTM) UTN-10 model having a load capacity of 100 kN. The tensile test was repeated on 4 specimens at identical conditions. During the test force absorbed by specimen on each 1 mm elongation to failure was measured to estimate tensile strength.

2.4. Microscopic Observations
The specimen for microscopic observation was made by first cutting the materials by hacksaw and it was roughly ground by wheel grinder. Then smooth grinding was done by three silicon carbide paper in grinding and polishing machine to scratches. The time of grinding in different point silicon paper is given in table 1.

| Grit Size of Silicon Carbide Paper | Investment cast material | Sand Cast Material |
|------------------------------------|--------------------------|-------------------|
| 320                                | 10 minutes               | 8 minutes         |
| 800                                | 8 minutes                | 6 minutes         |
| 1200                               | 8 minutes                | 9 minutes         |

Grinding was done as long as it was not found to be smooth so there was not the same time for grinding of specimens. After grinding the specimen, the specimen was polished on velvet cloth by spraying the Brasso solution as polishing suspension. To identify microstructure clearly, an etchant solution of 125 ml nitric acid and 125 ml distilled water was made. The microstructure of investment cast and sand cast brass materials were observed in 10 sec. etched sample on a metallurgical microscope.
3. Results and Discussions

3.1. Charpy Impact Test Result

The results of the Charpy impact test were in the form of energy absorbed. The results of investment cast material and sand cast material are given in table 2.

| Method of casting   | Specimens Number | Energy Consumed in Joule | Average Energy Consumed in Joule |
|---------------------|------------------|--------------------------|----------------------------------|
| Investment Casting  | 1                | 90                       | 71.5                             |
|                     | 2                | 53                       |                                  |
| Sand Casting        | 1                | 270                      | 162.5                            |
|                     | 2                | 172                      |                                  |
|                     | 3                | 30                       |                                  |
|                     | 4                | 178                      |                                  |

The average energy consumed in the investment cast specimen is less than that in the sand cast specimen. This may be due to the reason that investment cast specimens were from runner and riser part of Francis turbine while sand-cast specimens were from the casting of chips collected from machining of investment cast material though the conditions of casting were identical. In investment casting, the relatively larger and complex turbine was cast so there might be an improper flow of molten metal while casting. On the other hand, sand casting had been done in small size so there might be a proper flow of molten metal giving high strength than investment cast specimens. In sand-cast specimen-3, lower value of impact energy was reported which is due to the casting defects like the void and improper flow of molten metal.

Sensitiveness of V-notch of the specimens, zero error of the machine (friction losses), and parallax error while reading the value of energy absorbed were sources of error.
3.2. Compression Test Result

The results of the compression test were in the form of the ultimate compressive strength of the material. The ultimate compressive strengths were calculated by dividing the peak load by the original cross-sectional area of the specimen. The results are given in Table 3.

Table 3. Result of the compression test.

| Parameters                     | Specimen-1 | Specimen-2 | Specimen-3 | Specimen-4 |
|--------------------------------|------------|------------|------------|------------|
| Peak load (kN)                 | 314.40     | 330        | 346.50     | 293.50     |
| Ultimate Compressive Strength (MPa) | 1001.27    | 1050.95    | 1103.50    | 934.71     |

The average ultimate compressive strength was found to be 1022.61 MPa.

There were changes in the shapes of specimens after the compression test. Cracks occurred in specimen-1 and specimen-4. No cracks were seen in specimens-2 and specimen-3 but the change in shapes was observed.

![Crack in a specimen of the compression test.](image)

The materials were assumed to be brittle, the brittle fracture was not observed but slip dislocation was observed which may be due to casting defects in specimens.

There were followings sources of error:

- The compression cannot be noted with the corresponding variable applied load because there was no scale to measure a compression in the machine.
- Zero reference setting error.

3.3. Tensile Test Result

The results of the tensile test were in the form of forces versus elongation in mm. In each 1 mm of elongation, forces were noted and these forces were divided by the gauge cross-sectional area of specimens to evaluate stresses. For each elongation data point, corresponding strains were calculated by dividing elongation by the original gauge length. The stress-strain curve was obtained as shown in figure 8. The final result of each specimen was obtained in the form of ultimate tensile strength by the maximum value of stress before the failure of the specimen.

No necking was observed in the tensile test of specimens, and the stress-strain curve of all four specimens show brittle nature. In specimen-1, there was void at the cross-section of the fracture portion. It might be due to casting defects. Similarly, in specimen-3 fracture occurred near the grip section instead of the gauge section. This is also due to the casting defects and improper gripping.
Figure 8. Stress-strain curve for testing specimens.

Table 4. A result showing the ultimate tensile strength of specimens.

| Specimen | Ultimate tensile strength (MPa) | Average Ultimate tensile strength (MPa) |
|----------|---------------------------------|----------------------------------------|
| 1        | 194.29                          |                                         |
| 2        | 200.45                          | 224.24                                 |
| 3        | 222.72                          |                                         |
| 4        | 279.52                          |                                         |

Figure 9. Tensile test specimens after testing.

3.4. Microscopic Study Results

The microscopic views were observed by a metallurgical microscope for both sand and investment cast brass. The results of microscopic observation are given in figure 10.

The investigated brass is Cu-40%Zn alloy cast by melting 60% wt. scrap copper and 40% wt. scrap zinc. With reference to the Cu-Zn binary phase diagram, the solubility limit of Zn in Cu is around 35% and the cast brass material consists of 40% wt. Zn, the resulting microstructure of Cu-40%Zn alloy is in the alpha + beta region. The observed microstructure of cast Cu-40%Zn brass is illustrated in figure 10. Two-phase duplex microstructures could be identified: however, the exact composition of alpha and beta phases could not be evaluated due to the limitation of the microscope. This type of alpha + beta microstructure is known as 'Widmanstatten microstructure'. Alpha brass (FCC crystal structure) is
ductile at room temperature and capable of severe cold working without fracturing, whereas brass with higher beta (BCC crystal structure) content is less ductile when cold worked, however, has excellent hot working properties. The overall mechanical properties of brass alloy depend on alpha and beta composition. The amount of alpha and beta in the microstructure not only depends on chemical composition but also on the cooling rate. As the cooling during the investment casting process was kind of medium rate, the microstructure contained a slightly higher beta phase resulting in the relatively brittle brass alloy as compared to alpha brass [10].

**Figure 10.** Microscopic study of sand cast and investment cast brass etched for 10 sec 200X.

4. Uncertainties and Limitations
For the Charpy impact test specimens, the V-notch was made by hacksaw, so the exact dimension of V-notch was not ensured. The tests were conducted in an analog UTM machine lacking good calibration. The mobile camera was used for taking images of the microstructure of brass. For scaling, an image of 0.5 mm thickness metal was captured by a mobile camera and scale was drawn. Prepared specimens are not perfectly smooth, little roughness was present in the surface. The voids present internally while casting the specimens also contributes to uncertainty. Due to lack of brass material for making specimens, the chips originated while machining investment cast was collected and again these materials were sand cast to make testing specimens at the same condition as previous. Etching of specimens for the microscopic study was done based on the hit and trial method.

5. Conclusions
In the Charpy impact test, the energy absorbed in sand cast specimens is higher than the investment cast material due to the casting defects in investment casting. For specimen-1 and specimen-4 of the compression test, a crack occurred due to slip dislocation of specimens which might be due to casting defects. The stress-strain curve of all specimens shows the brittle nature of brass materials. In specimen-2 of tensile test specimen there was a void inside fracture section this is due to the casting defects in the sand casting process. In specimen-3 of the tensile test, the fracture occurred near to the grip section instead of the gauge section this is also due to the casting defects and improper gripping of specimen. The microscopic study shows the “Widmanstatten microstructure” so the properties of brass depending on the composition of the alpha and beta phase of microstructure. Since there is a higher beta phase which shows that the cast brass is brittle and also it validates the tensile and compressive testing results.
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