## 5.6. Ergonomic intervention in carpentry task

### 5.6.1. Designing of Chisel

Carpenters use many hand tools in their daily routine work. Importance of hand tools rises gradually in work sectors. Workers in small scale industry use hand tools in daily basis. Many of those tools are not created by using ergonomic principle which may produce interference between man machine interface the users. Thus it affects physiological and psychological health of the workers. The hand tools which are designed with ergonomic principle can avoid those kinds of health problems. Hand tools possessing ergonomic criteria becomes more compatible for the users that protects physiological and psychological health which ultimately helps to increase productivity (Stanton et al., 2004). The Ergonomic intervention for hand tools making is essential to weaken both the physical and mental exertion of the workers.

Chisel is one of the hand tools which is most frequently used by the carpenters. Chisel is used for verity of tasks in carpentry. Mostly it is used for designing on timber that is the most important part in carpentry work. Apart from designing it is used in other propose also, such as, it is used for giving particular shape and size of the wood etc. Chisel operators usually hold the chisel in left hand and hit on head of the chisel by a hammer which is hold by the right hand. Carpenters have to apply sufficient amount of force to hit on the chisel. The handle of the existing chisel which are available in the market, has a varied dimension and there is no particular grip area in chisel handle (Table 5.33).

During holding the chisel carpenters may feel pain/ discomfort in different parts of the hand and may have also griping problem due ti prolonged use of the tool. Ergonomic intervention may reduce such problems. An ergonomic design of the chisel may be undertaken to solve the above said problems in carpenters.

Reasons behind the redesigning of chisel –

- ➔ To lessen the pain/discomfort during performing chiseling task
- ➔ To reduce the musculoskeletal disorders in case of prolonged use of the tool
- ➔ To enhance productivity of the carpenters
- ➔ To reduce the risk factor of accident during performing the task.
- ➔ To provide comfort to the users.

In the present study an effort has been taken to redesign the carpenter's chisel from the view point of ergonomics. The following steps were undertaken:

### 5.6.2. Evaluation of conventional chisel:

The evaluation of existing chisel was carried out by the subjective and objective assessments. Ten numbers of existing models of chisel were collected from the market and different physical characteristics of those existing chisel were assessed. There was an appreciable characteristic variation in in the collected chisels, as presented in Table 5.33

**Table 5.33: Physical characteristics of collected conventional chisels**

| Model no. | Weight (gm) | Total length of chisel(cm) | Handle length of chisel (cm) | Diameter of handle (cm) | Shape of the handle | Grip of handle |
|---|---|---|---|---|---|---|
| 1 | 210 | 25 | 8.5 | 2.46 | Cylindrical | No grip* |
| 2 | 215 | 21.3 | 7.2 | 1.85 | Cylindrical | No grip* |
| 3 | 232 | 27 | 9.3 | 1.96 | Cylindrical | No grip* |
| 4 | 242 | 19 | 7.9 | 2.56 | Cylindrical | No grip* |
| 5 | 227 | 22 | 8.4 | 2.62 | Cylindrical | No grip* |
| 6 | 282 | 25 | 8.2 | 2.65 | Cylindrical | No grip* |
| 7 | 230 | 15.4 | 8.6 | 1.85 | Cylindrical | No grip* |
| 8 | 270 | 20.2 | 9.9 | 1.92 | Cylindrical | No grip* |
| 9 | 260 | 17.5 | 10 | 2.57 | Cylindrical | No grip* |
| 10 | 235 | 24 | 7.5 | 1.95 | Cylindrical | No grip* |
| Mean ±SD | 240.30 ±23.45 | 21.64 ±3.69 | 8.55 ±0.94 | 2.24 ±0.36 | - | - |

* **no** additional grip on the handle surface

It was found that the average length of the handle of the existing chisel was 8.55 cm, which varied from 7.2 to 10 cm. The results exemplified that the average diameter of the existing chisel handle was 2.24 cm with a variation of about 1.85 to 2.65 cm. there was wide variation in the weight of the chisel and it was found that the difference of light and heavy chisel was about 72 grams. It found that surface of the existing chisel handle was somewhat uneven also. It appeared that the physical characteristics of the chisel , particularly the handle, might be incompatible with the hands of the users. There should a standard dimension of chisel, so that it matches with the hands of the user because proper hand – tool (chisel) interface is essential for operation of the tool.

From the subjective study it was observed that the existing chisel had some difficulties. From the results it was detected (Table 5.34) that the chisel users felt pain at different segments of the body, e.g., wrist joint, palm, finger, and lower back portion. Results illustrated that the MSD was predominant in neck, shoulder joint and lower back of the workers.

**Table 5.34: Percentage of carpenters (chisel users) reported musculoskeletal problems in different parts of the body during using existing chisel**

| Body segments | Chisel users (n=33) | |
|---|---|---|
| | Frequency | Percentage (%) |
| Neck | 17 | 50.43 |
| Shoulder joint | 26 | 79.02 |
| Elbow joint | 20 | 60.39 |
| Wrist joint | 29 | 89.03 |
| Palm | 25 | 76.51 |
| Fingers | 27 | 82.34 |
| Upper back | 22 | 66.82 |
| Lower back | 29 | 87.18 |
| Hip | 16 | 49 |
| Knee | 7 | 20 |

About 89% chisel user stated pain in wrist joint and 76% and 82% of chisel user reported pain / discomfort in palm and finger respectively. Almost 87% of the workers informed discomfort at lower back. This type of pain / discomfort in the specific part of the body might due to physical exertion of load on the hand for frequent handling of chisel. Alongside this, the high prevalence of MSD was also noted in the wrist joint that might be due to frequent flexion at the joint. Marsot and Claudon (2004) reported that the occurrence of musculoskeletal disorders was related to the hand tool Design. Many more other investigations had determined that the bad designing of hand tool was a risk issue for musculoskeletal pain (Mulimani et al., 2014; Moore et al., 2016). It was also reported from other previous studies that the workers informed less uneasiness while using informed less uneasiness (Hunt et al., 2015; Söderback, 2009 and Dempsey et al., 2004). Hand tools have power to diminish the productivity of the workers if those tools are not ergonomically designed (Motamedzade et al., 2014; Kuijt-Evers et al., 2007 and Dempsey et al., 2004). Discomfort in different body segments could also reduce job satisfaction (Aazami et al., 2015; Liu et al., 2012 and Kuijt-Evers,2009). Previously designed hand tool had a serious problem for avoiding uneasiness and discomfort (Dempsey et al., 2004; You et al., 2005 and Jung et al., 2014). To overcome the said difficulties, in this study, efforts was made to reform the chisel handle from the view point of ergonomics.

From past few years, it was noted that importance of hand tools had stimulated towards the ergonomic desires of the operators, i.e., to ensure the work effortlessly, and comfortably. The tool would accomplish the job for which it was designed and corresponded to the features of the highest conceivable number of workforces (Marsot and Claudon, 2004, Kuijt-Evers et al., 2009).

But in India, industrial instruments and accessories are usually manufactured by people of tool-making families who differ in their acquaintance and individual experience of the tasks to be performed in making the diverse types of tools (Nair et al., 2017).

The occurrence of MSD in different body parts of the chisel users might be due to inappropriate fitting of existing chisel in respect to the dimension of the chisel handle with the body dimension of the carpenters.

The problems of the workers sustained till the termination of a work shift even after completing the work. A number of chisel users expressed that such troubles had happened due to recurrent use of the chisel (Table-5.35). Keeping all these difficulties in mind efforts were given to design the chisel which was used by chisel operators in performing the carpentry task.

**Table 5.35: Types and occurrence of overall pain / discomfort of the chisel users (n=33)**

**[Frequency and percentage (%)]**

| **Parameters studied** | | **Frequency** | **Percentage (%)** |
|---|---|---|---|
| Reported cases of feeling discomfort/pain | Yes | 30 | 92.03 |
| | No | 3 | 7.97 |
| Types of discomfort/ pain | Mild pain | 4 | 13.43 |
| | Moderate pain | 26 | 77.37 |
| | Uneasiness | 30 | 92.03 |
| | Severe pain | 13 | 39.64 |
| Other problems | Corm formation in hand | 23 | 70.43 |
| | Burning pain Sensation in hand | 23 | 68.94 |
| | Blister formation in hand | 17 | 50.62 |
| Discomfort continues till the end of work shift | | 24 | 73.29 |
| Discomfort continues after the work | | 9 | 27.45 |
| Whether discomfort / pain was due to handling of existing chisel? | Yes | 28 | 86.3 |
| | No | 2 | 5.94 |
| | Doubt about origin of pain | 3 | 7.76 |

Above table ( 5.40) represents the occurrence of overall pain / discomfort of the chisel user. From the observation it was noted that a notable percentage (92.03%) of workers felt pain during chisel handling. Among the total workers 92.03% of users reported uneasiness and 77.37% of users reported moderate pain during using chisel. A moderate percentage of workers reported other problems related to the chisel operation like, corm formation in the hand (70.43%), burning pain sensation in hand (68.94%) , blister formation in hand (50.62%). They also reported that the discomfort continued till the end of the work shift (73.29%) and even after the end of work (27.45). Finally the a large percentage (86.3%) of workers reported that the pain and discomfort was due to handling of existing chisel.

**5.6.3. Evaluation of Users' Gratification during using Existing chisel:**

The users' gratification on using the existing chisel was performed by noting the users' response after using the tool. In the table (Table 5.36 and Table 5.37) subjective responses of the chisel users regarding the appropriateness of different dimensions of existing chisel were noted.

The study was conducted on 33 randomly selected workers among previously selected chisel users. The workers were selected based on the alphabetical order of the names of the chisel users. The results showed that the chisel users also proposed some changes in the dimensions of the chisel (Table 5.36 and Table 5.37).

The results revealed that a greater percentage of the chisel users did not like the existing features of the chisel and suggested alteration in the length, diameter etc.

As stated earlier, the feeling of uneasiness was a personal experience when operating the hand tool (chisel) to make a job in a working atmosphere. Now-a-days ergonomists are giving emphasis on participatory method while designing hand tools. So, it was necessary to involve the worker in the design progress when individual desired to change hand tools that proposed coziness to the worker. The tool user's gratification was given preference to grow design ideas. In this present investigation, it was assessed by a questionnaire (Annexure-IX). Other scientists also used users' gratification and restrictions (Mohamed, 2012) for assessment of hand tool as well as for advancement of design idea (Groenesteijn et al., 2004 and You et al., 2005). Efforts were also made to change design thought from the view point of anthropometric principle. With this, the features or magnitudes of the hand tool finally assessed through subjective preference of the workers. In this context the psychophysical study of the users was carried out for selecting some of the chisel characteristics by paired comparison test.

The users also recommended their favored choice of physical magnitudes of the chisel as shown in Table 5.36. About 77% of the chisel users did not prefer the existing length of chisel handle and 79.3% of workers were not in favour of the existing diameter of chisel handle. A notable percentage of users desired modification in handle shape (76.76%) and grip (75.5%). Almost 54% of users favored the range of length from 12 to 15 cm and about of 75% of the workers favored for modification of handle diameter ranging from 3.5 to 4.0cm. More than 54% of chisel operators had a choice for concave cylindrical shape of the chisel handle. Moreover, about 75% of the chisel users had a choice of rubber grip on the handle of the chisel.

**Table 5.36: User gratification regarding physical dimensions of handle of the existing chisel (n=33)**

| Queries | | Users response (%) | |
|---|---|---|---|
| | | Handle Length | Handle Diameter |
| Preference of existing model | Yes | 22.8% | 20.7% |
| | No | 77.2% | 79.3% |
| Modification suggested | No change | 22.8% | 20.7% |
| | Increase | 77.2% | 74.19% |
| | Decrease | 0% | 5.11% |

**Table 5.37: User satisfaction regarding shape and griping of handle of the existing chisel (n=33)**

| | | Shape of handle | Grip of handle |
|---|---|---|---|
| Preference of existing model | Not have to modify | 23.24% | 24.5% |
| | Have to modify | 76.76% | 75.5% |

**Table 5.38: User preference (%) for the range of dimensions, shape and grip of the existing chisel (n=33)**

| Handle | | | | | | | |
|---|---|---|---|---|---|---|---|
| Length (cm) | | Diameter (cm) | | Shape of handle | | Grip of the handle | |
| Range | % | Range | % | type | % | type | % |
| 10-12 | 34.6% | 2.5-3.0 | 0% | cylindrical (same as existing) | 23.24 | Without grip (same as existing) | 24.5 |
| 12-14 | 53.9% | 3.0-3.5 | 8.3% | Balloon shape | 6.16 | Type I rubber grip | 75.5 |
| 14-16 | 11.5% | 3.5-4.0 | 75% | Concave cylindrical | 54.13 | Type II rubber grip | 23.96 |
| >16 | 0 | >4.0 | 16.7% | Convex cylindrical | 16.47 | Type III rubber grip | 51.54 |

After recognizing the problems of the existing chisel, efforts have been given to restructure the chisel on the basis of the different human factors like, dimension of the body, operator fondness and mode of chisel operation. Based on design concepts, some prototype models of chisel were made. The appropriateness of the measures ware verified later by means of psychophysical trials of the chisel operator. For this reason, paired comparison test was made. Dimensions of the body of the carpenters were used for shaping the physical dimensions of these tools. After provisional trial on those prototype models the final design was chosen.

**5.6.4. Design Approach:**

To built a smooth and securely handling tool, certain amount of design consideration was required. At present it was followed that importance on hand tool has moved more towards the ergonomic desires of the worker i.e., to ensure the task smoothly and securely. When general tools used by a varied range of workers, calculation of user’s populace statistics was important for industrial workplace and tool manufacturer because persons varied significantly in their anthropometric features (Okunribido, 2000 and Vyavahare and

Kallurkar, 2012). For this study before building a good user friendly hand tool (chisel) two design concepts were acquired. Those are as follows:

**5.6.4.1. Design Concept I:**

The existing chisel used in the carpentry task were manufactured by the local manufacturer without considering the human factors. As mentioned earlier there were many drawbacks in the exisiting tool and it suffered from incompatibility with the characteristics of human users. Therefore, a new ideation was employed to remove the incompatibility. In the new design idea, it was hypothesized that the dimensions and shape of the chisel should be well-matched with the body dimensions of the carpenters

In the first concept anthropometric principles might be employed for determining the physical dimensions of the chisel. The hand–handle interface should be considered according to the anthropometric dimensions of the user population. Appropriate percentile values of the hand dimension of the workers were required to be used to find the size of a particular part of the tool. For example, 5th percentile value of hand grip diameter could be used to fix the diameter of the handle of the chisel. Some of the dimensions of the chisel should be determined depending on the preference of the operators as well as on the necessity of the job.

**5.6.4.2. Design Concept II:**

In the second concept, biomechanical and safety factors had been considered. The shape and dimensions of different parts of the chisel were settled in such a way so that the hand arm system of the users remains in normal posture as far as practicable and the bimechanical stress could be reduced. The gripping of the handle might be an important issue for the operation of the tool. An addition, a rubber pad over the surface of the handle might ensure better grip which could prevent the slippage of the hand during gripping. There were chances of missing the head of handle of the chisel while hitting on the head by the hammer which could injure the left hand. To prevent such accident a flat safety cap might be added at the upper part of the handle.

**5.6.4.3. Anthropometric survey:**

Results of the anthropometric database of users represented the mean value and range of hand length, hand breadth, max hand breadth, hand grip circumference ,hand grip diameter of the both right and left hand of the users (n=70). Percentile values (**$5^{th}$, $50^{th}$, $95^{th}$)** of different hand dimensions were also calculated and the measures were presented in the Table- 5.39.

**Table 5.39: Anthropometric measure and percentile values of different hand dimensions of the chisel users (n=70)**

| **Anthropometric variables** | | | **Mean ±SD** | **Range** | **Percentile values** | | |
|---|---|---|---|---|---|---|---|
| | | | | | **$5^{th}$** | **$50^{th}$** | **$95^{th}$** |
| Height (cm) | | | 162.41±3.42 | 153-171 | - | - | - |
| Body weight (kg) | | | 51.42±3.518 | 46-62 | - | - | - |
| **Hand Dimension (cm)** | Hand length | Right | 17.72±1.02 | 15.71-19.63 | 16.01 | 17.63 | 19.15 |
| | | Left | 17.72±1.03 | 15.71-19.56 | 15.82 | 17.82 | 19.20 |
| | Hand breadth | Right | 7.89±0.41 | 7.23-8.71 | 7.21 | 7.8 | 8.7 |
| | | Left | 7.82±0.69 | 7.16-9.12 | 7.02 | 7.8 | 8.7 |
| | Max hand breadth | Right | 9.84±0.66 | 9.54-10.34 | 8.8 | 9.8 | 10.7 |
| | | Left | 9.79±0.71 | 9.23-10.19 | 8.6 | 9.8 | 10.68 |
| | Hand grip circumference | Right | 16.48±1. 35 | 15.32-20.20 | 14.23 | 16.4 | 18.0 |
| | | Left | 16.39±1.38 | 15.60-20.11 | 14.4 | 16.6 | 18.28 |
| | Hand grip diameter | Right | 5.24±0.43 | 4.58-5.47 | 4.08 | 5.22 | 5.73 |
| | | Left | 5.20±0.44 | 4.63-5.53 | 4.03 | 5.28 | 5.81 |

According to ergonomic guideline designing of the hand tool represented that appropriate fitting of the tool to the hand measurement was necessary because it was easy for an appropriate usage of the strength and gesture skills of the hand-arm system of the users.

Thus, it essential to acquire correct data for different anthropometric variables of the tool operators. Different anthropometric data like, hand length and breadth, maximum hand breadth, hand grip circumference grip, Hand grip diameter were used for determining the dimension of chisel. Percentile values of anthropometric magnitudes of the chisel users were determined (Table 5.39) and used for restructuring of chisel handle.

**5.6.4.4. Preparation of Prototype Models of chisel:**

In the present study, depending on design concepts, some prototype models of chisel were formed and verified. According to the concept-I four prototypes were made having different physical dimensions of chisel handle, viz., length, diameter and shape of the handle.

The shape and magnitudes of the dimensions of those prototypes are given in Table 5.40. Four modified models (MC1, MC2, MC3, and MC4) were prepared following the ideation in the concept.

On the basis of the design concept II, four types of prototypes were made considering the gripping feature of the handle. Four types of pads with different exterior textures were selected for gripping of the handle of the chisel, as presented in Fig. 5.1. By considering the concept I and concept II together, lastly four prototype models, viz., MC1, MC2, MC3 and MC4 were made. The physical dimensions and modifications of chisels are presented in Table 5.40 and shown in Fig 5.1

**5.6.4.5. Testing of prototypes: Paired Comparison Test:**

For testing of different characteristics of the prototypes psychophysical tests were employed. The paired comparison test, which was a powerful psychophysical test assessing the product, was used for that purpose. The details of the test has been discussed in section IV.

From the results of the pair comparison studies the design was reformed, wherever required. Each of the magnitudes/ features ware tested distinctly (Fig 5.3); for illustration, the length of the chisel was verified by varying the size of the length to find out the users' preference score. Then those prototype models of chisel were given to the workers and asked to do chiseling tasks for some time. The individual evaluation was done with those prototype models by using paired comparison tests.

**Table 5.40: Physical dimensions and other criteria of four prototype models of chisel**

| Model no | Handle | | | |
|---|---|---|---|---|
| | Length (cm) | Diameter (cm) | Shape of the handle | Grip of the handle |
| MC1 | 10 | 2.5 | cylindrical (same as existing) | Without grip (same as existing) |
| MC2 | 12 | 3.0 | Balloon shape | Type I rubber grip |
| MC3 | 14 | 3.5 | Concave cylindrical | Type II rubber grip |
| MC4 | 16 | 4.0 | Convex cylindrical | Type III rubber grip |

MC1 MC2 MC3 MC4

Fig 5.3: four prototype models of chisel

For this study ten chisel users were chosen randomly from the previously selected carpenters. The tests for different variables are discussed below:

Thus, different criteria of the design, viz., length, diameter, shape of the chisel handle were studied. These are discussed below-

**5.6.4.6. Handle Length of chisel:**

The handle length of the chisel is related to degree of comfortness during using the hand tool as well as to the work posture. As 77.2% of users advocated for alteration of the length of chisel, the preferred handle length should be determined. All of the users suggested to increase the handle length of chisel. For further verification the length was tested by psychophysical analysis of the subjects with the help of paired comparison test. The test was done to evaluate the appropriate handle length of the chisel by means of subjective preference.

The subjects were given four prototype models (as shown in Fig. 5.3) having variable handle length of the chisel from 10-16 cm (as stated in Table 5.40) and asked them to perform the chiseling work with those chisels. They were requested to assign a score in 10-point scale, as per protocol of the paired comparison test. The chisel operators selected for the test were requested to set their relative preference scores for each pair of the model. From assigned scores the resultant scores (Table 5.42) were calculated and plotted on subjective quantitative scale varied from -5 to +5 (Ebe and Griffin 2001) as presented in Fig. 5.4. The results illustrated that the modified prototype Model MC3, having the handle length of 14 cm, had got the maximum preference score of the chisel users. This result was in accordance with the earlier results of user’s satisfaction score (Table 5.41). The results indicated that when the chisel users performed their chiseling task with the said handle length, they could hold the chisel more comfortably than that of other prototypes.

**Table 5.41: Score assigned by the subjects (n=10) for handle length during performing paired comparison test**

| **Parameter: Handle length of chisel.** | | | |
|---|---|---|---|
| **MC1: 10.0 cm** | **MC2: 12.0 cm** | **MC3: 14.0 cm** | **MC4: 16.0 cm** |

| **Stimuli set** | **Subjects** | | | | | | | | | | **Mean** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| MC1:MC2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | -2.5 |
| MC1:MC3 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | +3.6 |
| MC1:MC4 | -1 | -2 | -2 | -1 | -1 | -2 | -2 | -2 | -2 | -2 | -1.7 |
| MC2:MC3 | -4 | -4 | -3 | -4 | -3 | -4 | -3 | -4 | -3 | -4 | -3.6 |
| MC2:MC4 | -3 | -3 | -2 | -3 | -2 | -3 | -2 | -3 | -2 | -3 | -2.6 |
| MC3:MC4 | -1 | -2 | -2 | -2 | -2 | -2 | -2 | -1 | -2 | -1 | -1.7 |

**Table 5.42: Resultant score of paired comparison test for handle length computed from Table**5.41

| Prototype models | MC1 | MC2 | MC3 | MC4 |
|---|---|---|---|---|
| Resultant score | +0.4 | +1.2 | +3.7 | -2.0 |

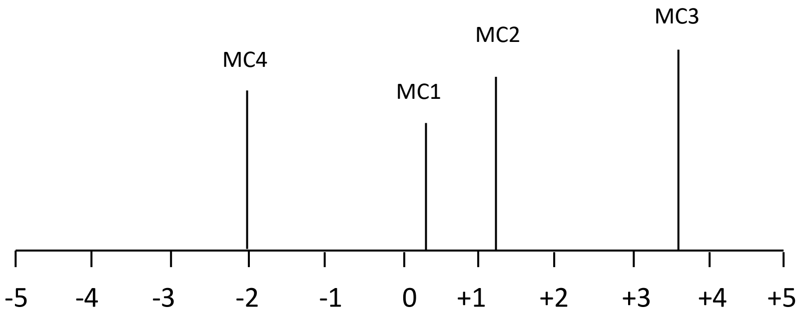


**Fig 5.4: Stimuli space of different prototypes for handle length of chisel**

**5.6.4.7. Diameter of Handle of the chisel:**

Setting the diameter of the handles of the chisel is a vital criterion as it is linked with the appropriate holding and gripping of the chisel.

The conventional chisel used by the carpenters had no even dimension in holding area of the chisel handle. The average diameter was 2.24±0.36 cm (Table **5.36**). About 79.3% of the chisel users were against the existing diameter of chisel and about 74.19% of them opined for increasing the diameter of chisel (Table **5.36**). In this study efforts were given to optimize the dimeter of the handle of chisel.

**Table 5.43: Resultant score of paired comparison test for handle diameter of chisel**

**Parameter: Handle diameter of chisel.**

**MC1: 2.5 cm; MC2: 3.0 cm; MC:3.5 cm; MC4: 4.0 Cm**

| Prototype models | MC1 | MC2 | MC3 | MC4 |
|---|---|---|---|---|
| Resultant score | +2.4 | +3 | +3.5 | +4 |

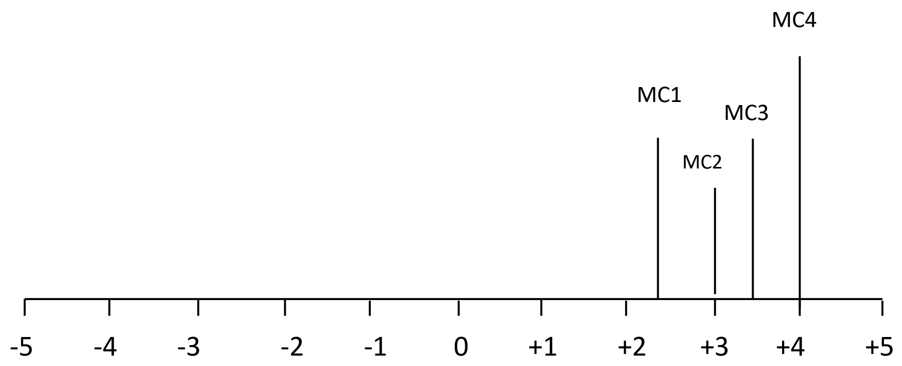


**Fig 5.5: Stimuli space of different prototypes for handle diameter of chisel**

To find out the proper diameter of chisel handle the paired comparison test was performed with four prototype models possessing different diameters (Table 5.40). The raw scores of the test are not shown here. However, the computed resultant scores of the pair comparison test were plotted on a 10-point scale, as presented in Fig 5.5 From the results of this test it was noted that the model MC4 (length =4cm) showed the highest preference score (Table 5.43).

From observation of a study (Kuijt-Evers et al.,2004) it was pointed out that the diameter of the hand tool ought to be such which allowed minor overlay of the thumb and fingers of a users with their hands. Proper diameter of the handle, as done in the present study, could satisfy such gripping of the handle.

In a previous study of designing hand tool, Pheasant and O‟Neill (2000) stated that appropriate diameter of handle might be well thought-out ideal for monotonous act and maximize grip force of the workers (Kong and Lowe, 2008; Seo and Armstrong, 2008). Lewis and Narayana (1983) described that a short grip area which did not extent the palm breadth, maximum forces were formed at the middle part of palm. Mechanical pressure might perhaps spread to the palm and fingers throughout using the hand tool. The surface of the tool handle is not just only visual but also useful (Fraser, 1983). A non-slip surface of the tool handle may also cover the skin of the handle and prevent change of hand location (Drury, 1983).

Extreme holding strength on hand which might also be a risk issue for the growth of MSD in the user's different body parts such as in hand, wrist and forearm and shoulder (Casey et al., 2002). Movement of the forearm and hand depends on 35 muscles, some of these involved in activity of gripping. During holding of tools handle, the flexor muscles in the hand and forearm generate grip strength although the extensors muscle of forearm steady the wrist (Hall, 2007). Ten intrinsic and nine extrinsic muscles are present in the wrist (Waldo, 1996). Through gripping actions each of these muscles was in their dynamic state.

The outcomes of this paired comparison test could be likened with the anthropometric data. The optimal diameter for a handles ought to be such that the muscles can perform the task or gripping activities with minimal force. Ideal handle diameter diminishes the force obligatory and permits the highest torque for gripping the hand tool, and also guards the underlying joint from injury, and decreases the risk factors related with frequent task requiring maximum grip forces and difficult postures. The grip diameter of the tool users was linked with diameter of the handle. In the present study the grip diameter was measured and the percentile value of it was used for optimizing the tools diameter, as discussed latter.

**5.6.4.7. Shape of the chisel handle:**

The shape of chisel handle is also related to holding the handle with proper grip. The shape of the handle should be appropriate for the palm of the user. Inappropriate handle shape of the chisel might affect the chiseling task and might also produce discomfort of hand arm system of users. The conventional chisels used by the carpenters, had no specific shape of the handle. However, most of the existing chisels had cylindrical shape, though there were variation in them. About 76.76% users were not satisfied with the shape of existing chisel handle. They were in favour of modification in the shape of the handle.

**Table 5.44: Resultant score of paired comparison test for shape of the chisel handle**

**Parameter: shape of the chisel handle**

**MC1:** Cylindrical (same as existing)**; MC2:** Balloon shape; **MC3:** Concave cylindrical**; MC4:** Convex cylindrical

| Prototype models | MC1 | MC2 | MC3 | MC4 |
|---|---|---|---|---|
| Resultant score | -2.2 | -1.3 | +3 | +1.7 |

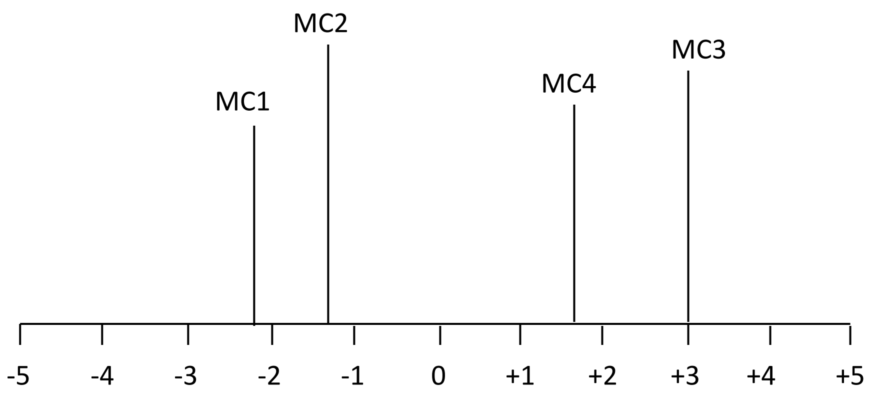


**Fig 5.6: Stimuli space of different prototypes for shape of chisel handle**

Four prototype models with different shape (MC1: cylindrical same as existing, MC2: Balloon shape, MC3: concave cylindrical and MC4: convex cylindrical) were made (Table 5.44). To find out the best preferred shape of the handle, paired comparison tests were made with those prototype models and the graphical presentation of the results of the test has been presented in Fig 5.6. From the results it was noted that the prototype MC3 had got the highest subjective preference score. So, prototype model MC3 that is concave cylindrical in shape was considered for the final design consideration of the chisel handle.

**5.6.4.8. Addon Pad in Grip Area:**

Griping strength of hand always linked with physical work which was measured as a potential predictor of general strength of human body. Healthy grip strength is desirable to successfully complete every single day-to-day industrial task using hand tools. Many research works described about the direct correlation among the grip strength, total strength of body and subjective performance (Sung et al., 1996; Orr et al., 2017). Grip strength had a vital character in preclusion of injury because during holding hand tools, it played an important role to keeping hand tools steady.

For using the chisel with existing handle there were couples of problems arise during gripping the chisel - due to sweating in the hand slippage of tool might be caused and secondly, uneasiness / discomfort was created for uneven and hard surface of the chisel handle. To overcome those problems, providing a pad on the handle surface, specially at the holding area of chisel may resolve the said problems. For the said purpose a rubber pad might be used on grip area of the handle of hand tools. Attachment of a gripping pad might cause uneasiness of the workers in some of the cases also. Some researchers found that the values of EMG of hand muscles were lower for using the rubber grip attached pliers (McBride et al., 2012). Howevr, in most of the cases adding rubber grip over the handle was beneficial for the task. It was noted that hand tools with rubber grip were favoured by the users (Seo and Armstrong, 2008). Addition of rubber pad in the hand tool grip area can hold the tool sturdily and also can significantly reduced fatigue in hand arm system during frequent uses of hand tools (Jaric and Uygur, 2013). Some of the scientists focused on the external texture, smoothness of the grasp pad to be beneficial which could take maximum forces, it also helped to resist slippage and provides better response to the hands (Cabibihan et al., 2015; Condon et al., 2014).

In this research study, gripping part of the chisel handle was covered with a rubber pad. Through the pair comparison test the necessity of rubber pad for gripping the chisel was verified. This test was made with two prototypes - one existing chisel (without grip pad) and one modified prototype chisel (with grip pad) to identify the benefit of handling the chisel with soft grip by user's preference scores of the chisel users. The computed scores were placed on the subjective scale (Fig 5.7). It was observed from the resultant scores that the higher preference score was given by the users for modified chisel (MC) with grip pad (GP) than that of existing chisel (EC). This specified that the chisel users favoured the chisel with a pad in the gripping area of the handle of the chisel.

**Table 5.45: Resultant score of paired comparison test for Grip of the chisel handle**

**Parameter: Grip of the chisel handle**
**No. of sample: 2 (Two).**
**EC: Existing chisel.; MC: Modified chisel with Grip Pad.**

| Prototype models | EC | MC |
|---|---|---|
| Resultant score | -2.8 | +3.2 |

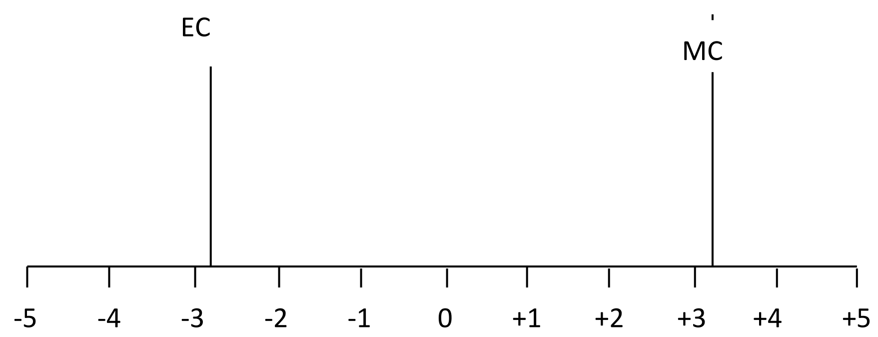


**Fig 5.7: Stimuli space of prototypes for grip of chisel handle**

One more criterion for choosing the grip pad was the texture of surface of the rubber pad. The ability of better tool handle griping depends on the external texture of the grip of the handle. Different grip pads with varied texture were covered on the gripping area of the chisel handle. To find out the preffered texture of the grip pad the paired comparison tests were done. Rubber pads with four different textures were selected for the test, as shown in fig 5.8

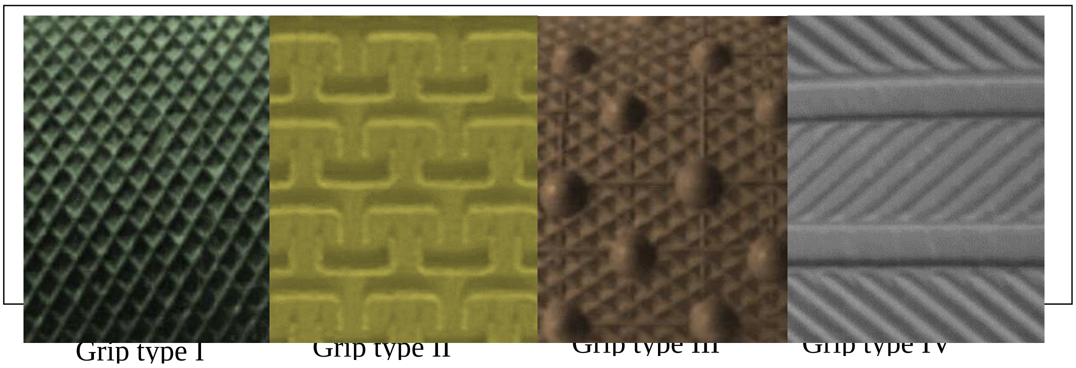


**Fig 5.8: Types of rubber grip with different superficial texture used on the handle of the chisel.**

The stimuli space of the paired comparison test of four different prototypes was placed in subjective scale, as presented in Fig 5.9. From the results it was shown that the highest preference score was noted in case of using the prototype MC4 (with Grip Type-IV). Thus, the rubber grip with slanting ridge (Grip Type-IV) with even interval exterior might be chosen for final design.

**Table 5.46: Resultant score of paired comparison test for grip pad of the chisel handle**

| Prototype models | MC1 | MC2 | MC3 | MC4 |
|---|---|---|---|---|
| Resultant score | +0.3 | +2.6 | +1.4 | +3.8 |

**Parameter: grip pad of the chisel handle**

**MC1:** Grip type I**; MC2:** Grip type II; **MC3:** Grip type III**; MC4:** Grip type IV

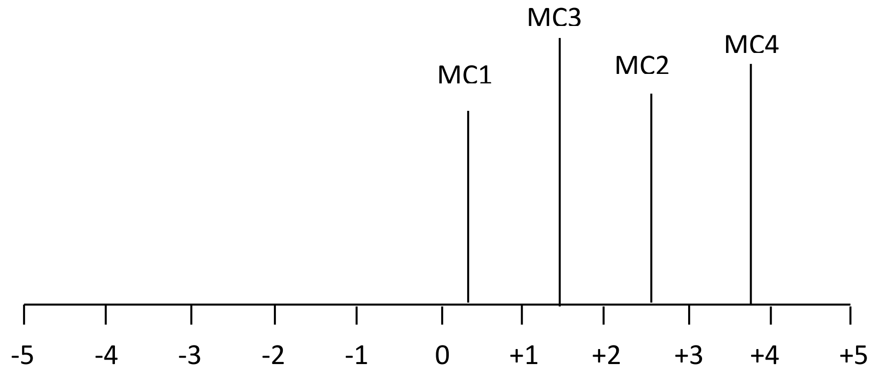


**Fig 5.9: Stimuli space of different prototypes for grip of chisel handle**

**5.6.5. Recommended Dimensions/ Characteristics of the Modified chisel:**

From the results of paired comparison test and different anthropometric dimensions of the carpenters, all design features of the chisel were carefully chosen. The final design criteria of the suggested model of chisel was presented in Table5.47. The handle length of the chisel was increased from that of existing one depending on the pair comparison test and 95th percentile values of the maximum hand breath. The existing average length of the chisel handle was 8.5 cm. From the results of the pair comparison test a handle length of 14.0 cm was found to be the best for the users. On the other hand, 95th percentile value of the maximum hand breadth might be suitable for the maximum percentage of workers for handle. The 95th percentile value of the maximum hand breadth was 8.7cm. With a clearance value of 5.0 cm ( 2.5 cm on each side) this value came to 13,7 cm, which was almost close to the value selected by the paired comparison test. Therefore, a value of 14.0 cm was the choice for the handle length.

Canadian centre for ooccupational health and safety (2016) stated from their tests that the use of a short handle can be the reason for unnecessary compression in mid part of the palm. The compression would spread the whole extent of the palm. So the tool holder must be designed to range beyond the hand when engrossed. One earlier study stated that the long-handled tools were more effective to operate the specific type of work (Yadav and Gite, 1982). Considering the above facts sufficient clearance beyond the hand under gripped condition was proposed. So, the handle length was further extended by 2.0 cm. Thus the final value of handle length was fixed as 16.0 cm (14+2 cm).

The grip diameter of the handle was chosen from the results of the paired comparison test. A diameter of 4.0 cm was selected as the prototype model MC4 having the said value of diameter showed highest preference score in this test. In addition to that the inner grip diameter of the subjects was taken into consideration. The 5th percentile values of the hand grip diameter was 4.03 cm. From the results of the users satisfaction study it was noted that 75% of users preferred 3.5-4.0cm. Therefore, it was noted that there was awell match among the computed $5^{th}$ percentile value of hand grip diameter , the results of paired comparison test and the range of user satisfaction score. As a rubber grip was wrapped over the handle a negative clearance of 0.5 cm was allowed. Considering all the above facts the diameter of the chisel handle was chosen. Therefore, the final diameter was established as 3.5cm.

The shape of the chisel handle was reformed from that of the existing one. The modified shape of chisel handle was established by the paired comparison test , that is, it was determined by the results of subjective preference of the workers. In the pair comparison test, the prototype MC3 having the shape of concave cylindrical got the maximum positive score. This concave cylindrical shape of the handle had the concavity in the middle part of the handle. So the upper and lower edge of the hadle remained elevated in comparison to middle part. The elevated edge , especially the lower elevated edge, acted as a guard for the hand grip and it could protect the hand from the slippage during its operation. Depending on the above facts the concave shape of the handle was finalized.

**Table 5.47: Selection of recommended dimensions of handle of tong on the basis of body dimensions and the results of pair comparison test.**

| **Dimensions of chisel** | **Required percentile of hand dimension** | **Results of paired comparison test** | **Clearance** | **Final dimension** |
|---|---|---|---|---|
| Handle length | 95th percentile of maximum hand breath (8.7 cm) | Best value: model no. MC3: 14 cm | +2cm | 16 cm |
| handle diameter | 5th - percentile of hand grip diameter (4.03 cm) | Best value: model no. MC4: 4 cm | -0.5cm | 3.5cm |
| Shape of the handle | - | Best value: model no. MC3: Concave cylindrical | - | Concave cylindrical |
| Grip of the handle | - | Best value: model no. MC4: Grip type IV | - | Grip type IV Alternate rive line grip |

The rubber pad having texture with alternate slanting ridge (Grip Type-IV) was selected from the the scores of the pair comparison test and attached to the handle of the chisel.

**Safety Guard**: A safty guard was introduced in the handle of the chisel. It was included in the upper part of the handle just above the grip area of the handle. It was made of rubber and it remained protruded from the handle surface. The protruded part of the guard could cover the fist under gripping condition. During the operation with chisel, the users had to hold the chisel by the left hand and the head of the chisel was hit by a hammer with the right hand.

The safety guard could protect the hand from the mishit of the hammer during doing work with the chisel. Thus any injury on hand could be avoided.

**Fabrication of the tool**:The recommendations for all the design criteria were taken together and the final design was made. The final dimensions and characteristics of the reformed chisel were shown in Fig. 5.10. The wood , steel made blade and good quality rubber pad were use as ingradient for the reformrd chisel. The tool was fabricated according to the

Fig. 5.10: **Recommended design of the chisel**


recommendations made from different tests.

As the redesigned chisel possessed the recommended criteria it might be helpful for decreasing the occurrence of pain /discomfort in hand arm system. Covering of rubber pad at holding part of the handle would lessen the slippage and help to grasp handle comfortably. Redesigned chisel helped to reduce the chances of slip and also the occurrence of injury by the hammer. Moreover, users should be motivated to use the restructured chisel in an appropriate way.

**5.6.6. Evaluation of Redesigned chisel**

After ergonomic modification of chisel the appropriateness of its use was verified by some studies. Those parameters of the studies are – subjective evaluation, percentage of occurence of pain and discomfort, pulse rate, and productivity.

**5.6.6.1. Subjective Study**

The redesigned chisel was given to the users for execution of their tasks and asked to opine about the affluence, coziness of work and acceptability of newly designed chisel. Those chisel users were asked to grade this modified chisel handle as 'bad', 'fair', 'good' and 'very good'.

**Table 5.48: Subjective assessment for modified chisel (figure in the parentheses indicated percentage)**

| **Workers** | **Grade** | | | | |
|---|---|---|---|---|---|
| | Bad | Fair | Good | Very good | Total |
| chisel users (n=50) | 3 (6%) | 6 (12%) | 34(68%) | 7 (14%) | 50 (100%) |

A large number of users expressed as “good” (68%) and some of them graded as “very good” (14%). About 12% and 6% of the users graded as “fair” and “bad” respectively. Hence, modified chisel was more acceptable to the users than that of existing one.

**5.6.6.2. Study of MSD:**

The redesigned chisel was given to the users for accomplishment their daily job for next three months. Then the occurrence of MSD in different segments of the body was evaluated during working with redesigned chisel and the existing one on a comparative basis and the subjective evaluation results was displayed in Table 5.49. The results illustrated that the occurrence of pain/ discomfort in different body segments of the users was lesser in case of handling modified chisel than that of the conventional one.To determine the significance level of difference of user's feedback regarding pain and discomfort rate, chi square test was performed between existing and modified chisel. It was observed that the rate of pain / discomfort at wrist and fingers of the users was significantly ($P<0.001$) lesser during use of improved model of chisel in comparison with that of existing one. A significantly lower ($P<0.01$) prevalence of MSD was noted in palm and shoulder for using modified chisel handle than that of existing tool (Table 5.49). So, results proved that with a lesser degree of distress, specifically in the hand-arm system was noted among the chisel users while they performed their work with modified chisel.

**Table 5.49: Percentage of incidence of discomfort/ pain in different body parts of chisel users (n=25) diring handling existing and modified chisel**

| Body segments | Existing chisel | Redesigned chisel |
|---|---|---|
| Neck | 43.66% | 35.34% |
| Shoulder joint | 70.15% | 49.27% * |
| Elbow joint | 58.34% | 39.17% |
| Wrist joint | 92.21% | 42.35% ** |
| Palm | 78.45% | 32.24% * |
| Fingers | 70.55% | 25.49% ** |

* $p<0.01$, ** $p<0.001$; $\chi 2$–test w.r.t. existing chisel.

**5.6.6.3. Study of Heart Rate:**

The heart rate of the chisel users was measured during resting and chiseling while using existing and redesigned chisel and the results have been represented in Table 5.50. It was found from the results that the mean working heart rate of the workers was significantly ($p<0.05$) lesser during performing the task with modified tool in comparison to the existing tool. From the resting and working heart rate the cardiovascular stress index (CSI) was determined. A significant ($p<0.05$) decrease in the value of CSI was observed in case of using modified chisel in comparison with that of existing chisel. Thus it was appeared that the cardiovascular stress of the users was reduced while using modified chisels.

**Table 5.50: Resting and working heart rates and CSI of chisel users (n=25) during operation of existing and modified chisel**

| Types of chisel | Heart rate (beats/minute) | | CSI |
|---|---|---|---|
| | Resting | Working | |
| Existing chisel (EC) | 74.40±6.08 | 118.24±9.14 | 32.14±9.40 |
| Modified chisel (MC) | 74.40±6.08 | 110.66*±9.42 | 27.31*±9.07 |

*p<0.05

**5.6.6.4. Productivity Study:**

The productivity study was made during using modified chisel by the users and it was compared with that of existing one. The productivity was assessed by measuring the chisel work done on the area of wood per unit time. The results of the productivity study have been displayed in fig-5.11. The results revealed that the productivity was augmented by 13% during using modified chisel in respect to that of existing hand tool. So, from the view point of productivity study it may be concluded that the modified chisel helped the carpenter to perform better than than that of existing one.

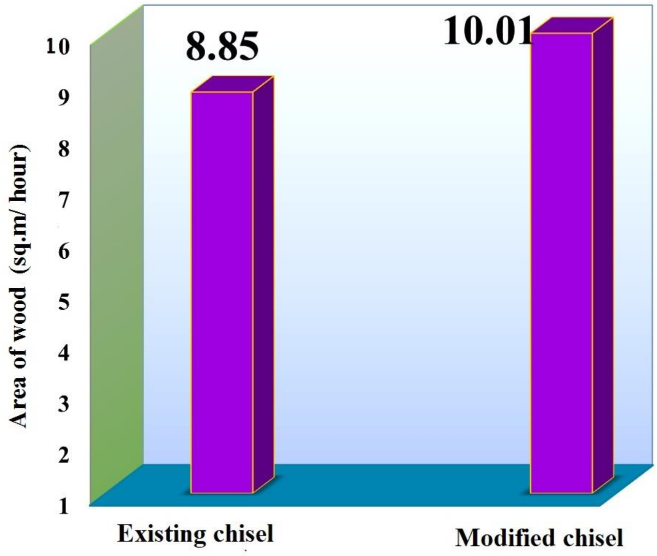


**Fig 5.11: Mean productivity (area of of wood finished per unit time) with existing and modified chisels (n=25).**

**5.6.7. Analysis of Cost of the Modified chisel:**

It is necessary to evaluate the production cost of the redesigned chisel. Total making cost of modified chisel was calculated and compared that amount with cost of existing chisel. The results have been given in Table 5.51. It was noted from the results of cost analysis that the amount of making cost for modified chisel was little higher than that of the conventional chisel. Due to addition of rubber grip the production cost for modified chisel was enhanced. As the hiking of price was very little and also there was increased productivity with this modified model, so it would be easily affordable by the carpentry shop owner.

In addition to that the medical expences of the carpenter was another factor for cost analysis. By interviewing chisel operators, it was known to us that the workers had to bear a relatively higher amount of medical expenditures due to work related pain and injury during using the conventional chisel.

**Table 5.51: Cost analysis for modified chisel**

| Items | Existing chisel | Redesigned chisel | Relative gain (+)/ loss (-) in redesigning chisel |
|---|---|---|---|
| **Iron material cost (INR)** | 50 | **INR** 50.00 | - |
| **Wooden materials for handle cost (INR)** | 20 | **INR** 20.00 | - |
| **Rubber Grip cost (INR)** | | **INR** 30.00 | -30 |
| **Making cost (INR)** | 20 | **INR** 20.00 | - |
| **Total making cost** | **INR** 90.00 | **INR** 120.00 | +30 |
| **Medical expense/month *(Rs)** | 300 | 40 | +260 |

It was noted that the during using modified chisel, medical expenses of the workers was diminished in respect to that of the existing chisel. Considering the medical expence of the workers the total cost of the modified chisel was lesser (INR 260/-) than that of using conventional chisel. On the other hand the modified chisel yielded better productivity as the worker earned more by using modified chisel. Using modified chisel, the workers could save medical related monthly expenditure of about INR 260/- .Hence, it was demonstrated that the modified chisel users became benefited in their income due to improved productivity.