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Experimental Investigations into Manufacturing Processes Used to Produce Musical Steel Drums

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Abstract: *This paper explores innovative manufacturing processes, which can be used to manufacture the national musical instrument of Trinidad and Tobago, the Musical Steel Drum or Steelpan. The main manufacturing process used today is the manual or Handforming technique. In order to achieve more consistent and deeper formed components while maintaining the high quality of the instrument, it is proposed that the Marforming process and the Flowforming process, an adaptation of the Spinforming process be used to replace the traditional Handforming method. Experimental investigations using the Flowforming or Spinforming and Marforming processes proved to be promising in achieving the required strain distribution of the formed component. Evaluation took the form of strain analyses of preformed steel drums. It was found that the Marformed components had the smallest range of % strain values while the Spinformed components had the largest range.*

Keywords: *Musical Steel Drum, Steelpan Musical Instrument, Handforming, Marforming, Flowforming, Spinforming, Trinidad and Tobago*

1. Introduction

The Musical Steel Drum, or Steelpan, is a unique instrument, and one of the most recently invented. Traditionally it is skillfully hammered from a 55-gallon cylindrical oil drum having a diameter of 57.8cm (22¾ inch), which has been carefully fashioned and tuned to produce musical tones. Musical Steel Drums carry the full chromatic range of notes, and can be used to produce just about any type of music one desires (Lewis, 1993). The Steel Drum is the newest instrument in the world, having its origins in the late 1930's. In just over half a century, the Steelpan musical instrument has spread all over the world, gaining popular acceptance as a serious musical instrument (Lewis 1993). It can be found in reggae bands, rock groups, classical ensembles, jazz combos, and most other forms of music (Lewis *et al*., 2005).

When applied to the making of the steelpan musical instrument, manufacturing methods today are not what it was three decades ago. Manufacturing practices that were effective in the past will no longer be so in the future. The traditional method of manufacturing the steelpan was by 'dishing out' a bowl from an oil drum and hammering out the notes. This handforming method is very time consuming, noisy and labour intensive (Lewis and Ameerali, 2006).

As the Global Village expanded to include foreign investors and researchers, more innovative and cost effective methods were developed and tested to make the steelpan musical instrument a viable product. Researchers have already proposed and tested new manufacturing methods such as Spinforming, Flowforming, Aqauforming, and Marforming to name a few. Although these manufacturing methods have been in existence for some time, their potential advantages have only been recently realised in the fabrication of the steelpan musical instrument.

A number of books have been written on the development of the musical steel drum (Elder 1972; Blake 1996; Fletcher and Rossing, 1991; Kronman 1995; Gay 1998; Bullour *et a*l., 2006; Wilkins and LaRose, 2006). The following gives a brief history of the steel drum and the developments that led up to the instrument as it stands today:

During British Colonial rule of Trinidad and Tobago in the 1800's, hand drums were used as a call for neighbourhood gangs to gather and have street fights with other gangs. Hoping to curb the violence, the government outlawed hand drums in 1886. Deprived of the drums, the Afro-Trinbagonians turned to the "Tamboo Bamboo", where each member of a gang would carry a length of bamboo and pound it on the ground as the group walked through the streets, producing distinctive rhythmic ‘signatures’, which identified each gang. When two gangs met on a march, they would pull out the machetes they had hidden inside the long bamboo poles to start a street fight. Since this only contributed to the violence, the government soon outlawed the Tamboo Bamboo. Deprived of all traditional rhythmic instruments, the Trinidadians took any objects they could find, including garbage can lids, old car parts, and empty oil barrels (from the Navy bases on the island). They used these instruments to form the Iron Bands, which marched down the streets playing the same distinctive rhythms.

One day in the late 1930's, during a particularly rough Iron Band session, somebody discovered that a dented section of barrelhead produced a tone. Winston "Spree" Simon is generally credited with being the first person to put a note on a steel drum. Originally the musical steel drums were convex, like a dome rather than a dish. Elliot Manette, a pan-maker still active in the US today, was the first to “dish out” a drum and give the musical steel drum its mature form. In 1946 the Invaders steel-band orchestra, led by Elliot Manette, was reported to be the first steel band to participate in “organised mas.” Many tuners began experimenting with and producing tuned 'pans', eventually forming large groups of the neighborhood pan men into orchestrated bands.

The musical competitions that began to take place each year at Carnival quickly replaced the street fights. In 1948 the 55-gallon oil drum finally became the main raw material for making the musical steel drum. The first fourteen-note steel drum with chromatic tones was developed. There were two competitions, one for the popular songs of the year, and a separate contest that showcased both the technical ability of each band and the versatility of the steel drum musical instrument by presenting highly orchestrated classical pieces. Fifty years after the first such contest, the rivalries between Steel-bands still exist, but manifest themselves in an excellent quality of musicianship culminating in the “Panorama Steel-Band Competition” each year around Carnival time.

The bands, which include Phase Two Pan Groove, the bpTT Renegades, the Trinidad Cement Limited Skiffle Bunch, and the Silver Stars, each performs a masterfully arranged piece for these competitions. Each big band contains over 100 musicians and 300 pans, and rehearses relentlessly for months before Carnival in the hopes of winning the Panorama Music Competition and being crowned champion steel band for the year.

In the summer of 1996, a unique collaboration began at The University of Texas at el Paso (UTEP) combining performance and research of the Caribbean Steel drum (Murr *et al*., 1999a). Professors Larry White of the Department of Music and Lawerce Murr of the Department of Metallurgical and Materials Engineering formed the UTEP Performance and Research Teams. The teams realised that there was little investigation done into the metallurgy of this musical instrument and that the musical steel drum was developed purely by trial and error (Murr and White, 2000). The group noted that the acoustical properties of the musical steel drum had been documented by Hansen et al (1995) and thus wanted to link the acoustical properties and metallurgy of the steel drum. They noted that the development of the instrument was a complex, non-linear metallurgical process including strain hardening and strain ageing (Murr *et al.*, 1999b). The sinking process had been examined using light metallography (LM) and a transmission electron microscopy (TEM) to characterise residual microstructures corresponding to reductions in thickness of up to 50% at the bottom of the drum head. This revealed that deformation had an important effect on the acoustic spectrum, especially harmonic spectra. Harmonic node splitting was observed for thin circular plates and they observed that there was a frequency difference of 60 Hz at 20% cold reduction and 160 Hz at 40% cold reduction. It was noted that these dispersion effects, due to deformation induced microstructures as well as irregularities in the note geometries and thicknesses, point to the complex and nonlinear acoustic features that contribute to the sound of the steel drum.

The group also reported that the heat treatment of the steel drum was found to involve strain ageing with the optimum conditions at approximately 350 C for 10 minutes and either water quenching or air cooling with the ageing effects ranging from 5-20% (Murr et al., 1999a). The strain ageing combined with the strain hardening applied to the drum head sinking and note fabrication processes, produces a requisite elastic–plastic interaction which allows for multi-harmonic tuning and the creation of unique chromatic tones and overtones that are characteristic of the various instruments.

Hansen et al. (1995) conducted a study on the tuning and mode of the musical steel drum. They discovered that areas, which undergo significant bending, and displacement exhibit greater pitch changes resulting in changes in stiffness and mass distribution, whereas changes in a region or nodal line will not affect the frequency of that mode significantly. Further to this, Hansen et al. (1995) investigated the effect of firing the steel drum. It was noted that after heating, the modal frequencies increased by 10-30%, indicating that the Young’s modulus of the steel drum had increased. It was also noted that further working of the metal during tuning partially softened it, but the metal between the notes appeared to remain hard. Some steel drum makers also preferred to harden the surface by heating the drum in either a nitrating bath or in a nitrogen atmosphere. This was desirous since the aim of the manufacturing process was not to create a flexible core for easy tuning but to create a hard surface that resists mechanical deformation when played.

2. The Making of A Steelpan

In the hand-forming process, the flat surface of a 55-gallon oil drum is sunk using a series of hammers, starting with a 3.6 kg (8 lb) sledge hammer and continuing with hammers of decreasing weight until the surface resembles that of a concave bowl. Notes are then marked and grooved out using a dull punch to avoid bursting of the surface. Eleven (11) steps involved in the making of a steelpan are as follows: Choosing the drum; Finding and marking the center; Sinking the drum; Counter sinking; Grooving the Steelpan; Cutting the drum; Cutting the skirt length; Burning the Steelpan; Tuning tools and instruments; Tuning the Steelpan; and Blending the Steelpan.

Sinking of the drum generally begins using a 3.6 kg (8 lb) sledgehammer. As the bottom of the drum gets deeper, lighter hammers are used because the metal gets thinner as it is stretched, so less force will be needed. This process is time consuming and extremely noisy, and can affect the craftsman's hearing if proper steps are not taken to safeguard it.

After sinking and cutting the pan, the steel must then be tempered to increase the resilience and strength of the metal. A hammer is used initially to "bring in the note". The note area is constantly tested with a pan stick while hammering and an electrical instrument called a strobe is used to get the accurate tone of the notes.

When the pan is finished tuning, it is chromed. Chroming the pan enhances both its aesthetics and tonal quality. Each pan can take up to a week of hard work to finish with the most time consuming steps being the sinking, counter sinking and grooving the steel drums. Figure 1 shows a sketch of a steelpan.

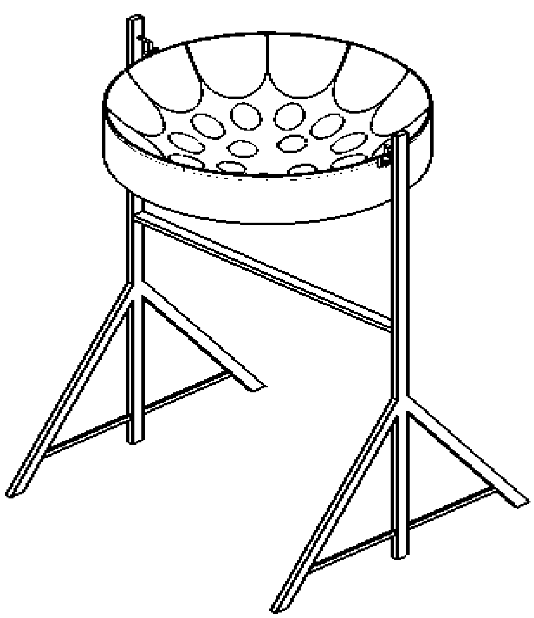

Figure 1. A sketch of a Steelpan mounted on a playing stand

Figures 2 and 3 show a top view of a tenor pan and a front view of the tenor pan. Music is produced by striking the notes of the musical steel drum with wooden sticks with strips of rubber rolled at the ends.

The following sections deal with how the Spinforming and Marforming processes were introduced into the manufacture of the steelpan in order to reduce the time for completion.

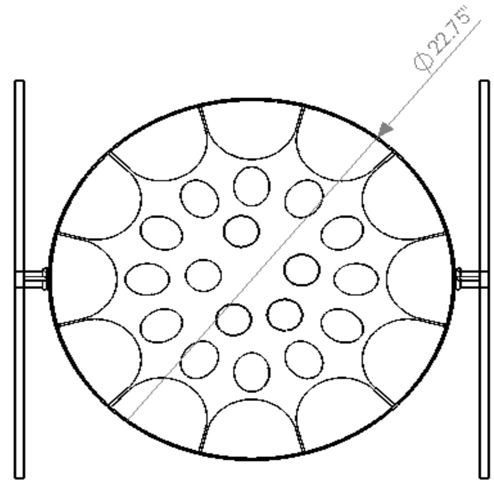

Figure 2. Top view of a tenor pan

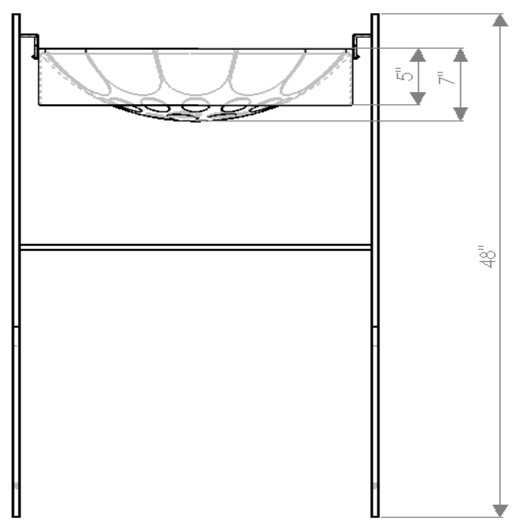

Figure 3. Front view of the tenor pan

3. The Spinforming Process

In the traditional Spinforming technique material is pushed from the outer circumference of the metal disc to the center in progressive passes of the former. This results in a thinning of the outer region of the formed component with a thicker center. The opposite is required for the musical steel drum and in an attempt to achieve this, the required strain distributions of the finished component were initially compromised with severe thinning of the sheet metal. Spinforming is a cold forming method in which a rotating disc of sheet metal is drawn over a male die. The work is carried out on a high speed lathe except that in place of the tailstock, the lathe has some means of holding the work against the form. Pressure is added using a round-ended wooden or metal tool. As the metal rotates, the craftsman applies pressure to the disc causing it to flow against the form. In most cases the metal is kneaded to and fro to produce the desired thickness.

A considerable amount of skill is required by the operator so as to prevent buckling of the formed piece. Lubricants such as soap, beeswax, and linseed oil are used in this process to reduce the friction between the former and workpiece. The spinforming process is limited to symmetrical components and most spinning work is done on the outside diameter, although inside work is possible as with the case of the musical steel drum where the material is worked from the center outwards.

Just over twenty-five (25) years ago, employees of Metal Industries Corporation (MIC), Trincity Industrial Estate, Trinidad, and staff members from the Department of Mechanical Engineering at The University of the West Indies got together and came up with the idea of making the steelpan using the Spinforming process. They noted that too much time was consumed in the sinking of a barrel to make the steel drum. It also entailed a lot of manual hard work to groove the notes and at the end of it, one bad stroke with the hammer would burst the pan. Due to these time consuming activities, they thought about pre-forming the bowl or dish for the tenor pan using a variation of the Spinforming process.

Firstly, discs used to form the tops of the drums were obtained. These discs were then connected to a high-speed lathe and the whole system was modified to give the required shape. In the initial setup, no backing was used so the disk had to be pushed into shape and checked each time with a tenor pan to observe when the shapes were fairly close.

The problems encountered with this were:

1) The type of roller initially used was cutting into the pan surface and formed grooves that could not be ironed out to give a smooth surface on the pan.
2) Cracks were developing in the surface.
3) There was no backing for the finished product to rest on to give the desired shape.

Using this information together with the results from the first set of pans that failed, a wooden dome was made to the actual profile of the desired end product. The roller used was changed to give the edges a smooth surface. The lever used to push the material was extended to approximately four meters long and heavy-duty oil was used to lubricate the surface. The advantages with this process included:

1) Preformed bowls could be made faster than with the handforming method.
2) With the Spinforming process the thickness variations would be closely controlled during the manufacture of the instrument whereas this may not be true about the hand formed pan.
3) There is greater control in stretching the pan in Spinforming as compared to the traditional method.

4. The Marforming Process

The Marforming process can also be used in manufacture of the steelpan musical instrument. This process operates using the principle of rubber pad forming techniques. In this type of forming, the die rig employs a rubber pad as one tool half and a solid tool half to form a component into its final shape. The solid tool half is similar to the die in a conventional die set. In this case it has the concave shape of the steel drum. The Marforming process was developed to apply the inexpensive tooling of the Guerin and Verson-Wheelon processes to deep drawing and forming of wrinkle free flanges.

The process also incorporates the use of a pressure controlled blank holder. In this process the die is fixed and the flexible rubber punch descends on the die and deforms the sheet metal. In this process the die has the shape of the dome of the musical steel drum with some notes pre-marked on it. Hence the sheet metal, when deformed, will take the concave shape of the steel drum. This will eliminate the manual sinking process and thus assist the tuner in marking the notes.

Begeman (1963) noted that the Marforming process aids in deep drawing of odd shaped parts. The process is superior to the Guerin process since it does not allow the pressure on the blank to build up so as to form wrinkles. In Doyle's (1969) text, he stated that the forming pressure usually lies in the range between 34-55 MN/m^2 (5500 – 8000 psi). Parts that can be produced included flanged cups, spherical domes and many other non–symmetrical shapes. It is more suitable for deep drawing and gives better definition to shallow forming as compared with rubber pad forming. Morris (1955) noted the advantages of using the Marforming process include low tooling costs with deep draws of complex shapes.

In the following section, data collected and comparisons made between the Handforming process, Marforming process and the Spinforming process are presented along with an evaluation of each process.

5. Analysis Of Data

The manufacture of the steelpan musical instrument using the handforming process has evolved through trial and error. The strain profiles of the bowl produced by the handforming process are compared with the strain profiles of the bowls obtained by the Marforming and Spinforming processes in order to determine which process can best match the thickness strain profiles of the handforming process and reproduce the metallurgical characteristics achieved by this process.

Equal distances were marked off on the outer perimeter of the specimens used. Lines were then scribed passing through the centre to connect the corresponding points. Individual sectors were then labeled from 1 to 12. A line drawn through the sector was divided into 5cm intervals starting from the tip of the sector up to the end. A small concentric circle of diameter 8mm was then drawn at these 5cm marks. The circles were then divided into four equal parts. Readings were taken at four points using the sheet metal micrometer and the average used. The same procedure was carried out for all twelve sectors. The original thickness of these specimens was then measured at the perimeter where no forming took place. Figure 4 shows the drawing of a sector prepared for taking readings.

The thickness strains for components formed using the Handforming, Marforming and Spinforming processes were calculated after data on the thicknesses of sections of formed components using the three forming methods had been collected (see Tables 1 and 2). The thickness strains were then plotted against the distance from the center for the steel drums used in this experimental investigation. It can be seen from Figure 5, that there is a decrease in the strain from the center of the Spinformed component to the perimeter (i.e. 5 cm to 25 cm from the center). The values of the % strain ranged from -15.0% to -3.0%.

As one moved away from the perimeter of the pan towards the center, the thickness of the spinformed piece decreased. The highest thickness strain was attained at the centre of the component. The range of strain values that were attained for the handformed pans was between 5.0% and -0.6%.

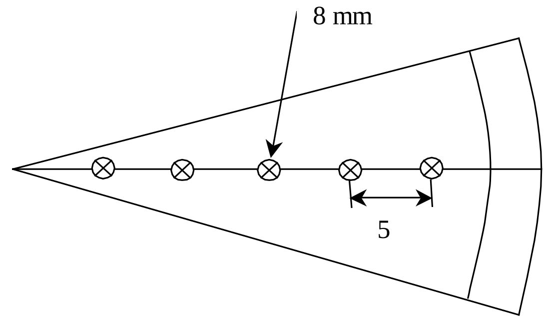

Figure 4. A sector prepared for taking readings

The type of graph that was attained was very much different to the spinformed one and did not show any general trends. When analysing this graph it was clearly seen that there was predominantly negative straining taking place.

The % strain distribution for the Marformed components and Handformed components followed a similar trend. The strain values attained for the graphs were mostly negative. The values were in the range -6.3% to -0.2%. This was a very narrow region of strain in which the values attained were situated.

6. Discussion

From the summary of results obtained it is observed that components from the marforming process had the least strain variation over the entire specimen area. From the theory behind the application, the rubber will exert an equal and opposite pressure across the entire blank area when compressed by the punch. This resulted in the blank taking the shape of the punch.

Table 1: Thickness values before and after forming

Distance from centre of drum /cm	**Original Thickness / mm**			**Final Thickness / mm**		
	Handformed	Spinformed	Marformed	Handformed	Spinformed	Marformed
5	0.525	0.525	0.523	0.497	0.446	0.490
10	0.526	0.525	0.523	0.459	0.451	0.475
15	0.525	0.525	0.523	0.499	0.461	0.496
20	0.525	0.525	0.522	0.511	0.477	0.508
25	0.526	0.525	0.523	0.523	0.509	0.522

Table 2: Thickness strains samples for each forming method

Distance from centre of drum /cm	**% Thickness Strain**		
	Handformed	Spinformed	Marformed
5	-5.3	-15.0	-6.3
10	-12.7	-14.1	-9.2
15	-5.0	-12.2	-5.2
20	-2.7	-9.1	-2.7
25	-0.6	-3.0	-0.2

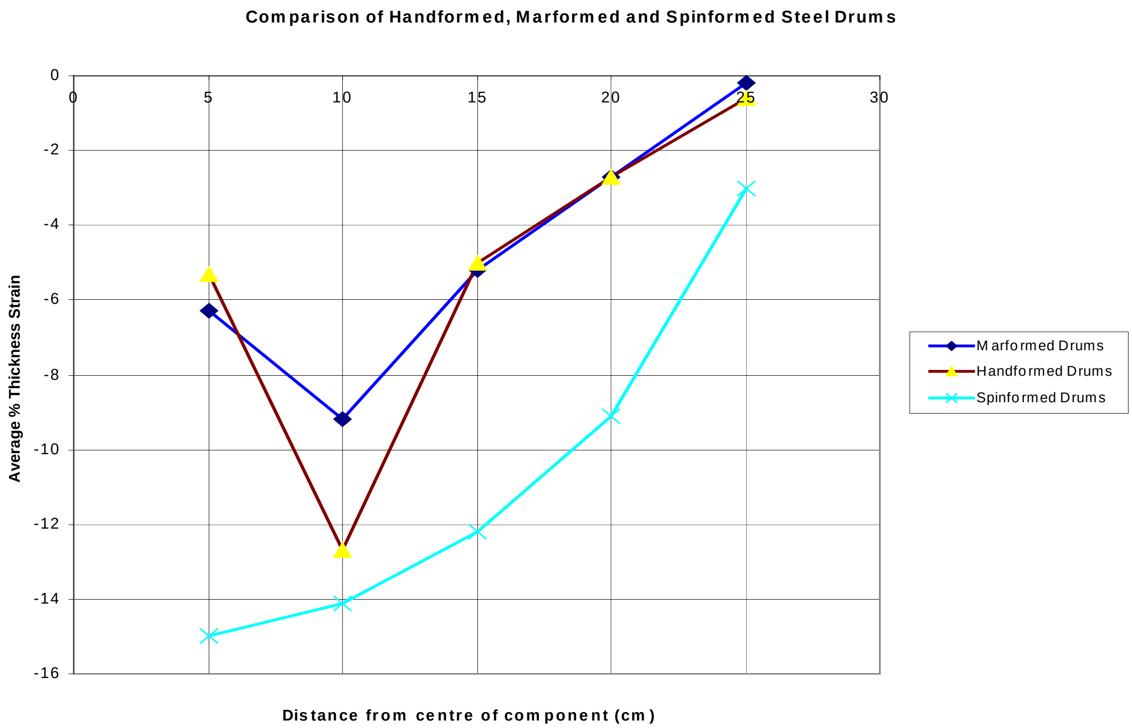

Figure 5. Comparing strain distribution of Handformed, Marformed and Spinformed Drums

The spinformed components contained a uniform region in which the thickness was fairly constant. The thickness of the specimen in this case was controlled via the use of a "former" on a supporting shaft. The diameter of the former is crucial to the development of a good spinformed specimen. If the former is too large then it will exert a pressure over a large area at any one point in time. This may lead to the formation of radial "buckle" lines on the surface of the formed piece. These buckled regions are very difficult to remove and in most cases the specimen must be discarded. If however the former is too small the pressure exerted on the blank surface area will be very high. This will cause the ball to become very hot and if the ball remains in contact with the spot for a long period of time there could be "fusion welding" taking place. The small surface area of the ball is not large enough to push the material being formed; in some cases "chattering" of the ball may take place.

Spinforming is a very versatile process in that it allows the operator to control the thickness of the specimen. Depending on the strain requirements, the operator is capable of making certain regions of the specimen thicker or thinner than others. Spinforming allows the operator to literally move material from one region to another. This movement of material is known as "kneading" of the material. During this process the "former" is moved forward and back across the entire specimen repeatedly. The region that has to be thinned is located and the procedure is carried out within this area. This will help to explain the positive and negative strain values attained from the spinformed specimens. It should be noted that to obtain this strain distribution, the operator has to exercise considerable skill in the forming process otherwise the material may tear due to excessive thinning and the component would have to be discarded.

The production time is dependent on both the size of the component being produced and the number of intricate sections the specimen contains. The time taken to produce a bowl using the marforming process was approximately 20 seconds for a single component from a given blank. The production time when using the spinforming process under similar conditions was approximately 10 minutes. The longest production time occurred with the hand formed pans, which usually taking a few days.

The component produced using the manual forming method is versatile since it can be made in any size, shape or form. No limits are set on the products formed using this method. However it is very difficult to control the thickness of a hand formed specimen. The formed component in this case is controlled by manual methods. The operator does not have the capabilities to determine the required thickness. In most cases the operator's perception of the thickness is directly related to the pressure he/she is capable of applying at any one point in time.

The setup times for these processes vary. The manual forming method will require the least setup time. The material to be formed is placed on a workbench or some supporting mechanism after which the forming process starts. The setup time for Spinforming is dependent upon the size of the blank being used. The setup time can vary from 5 to 10 minutes. The marforming process has the longest setup time of the three. This is partly due to the fact that the punch is located on the die rig. The die has to be disassembled before removing the punch and replacing it with a new one. This process can take hours depending upon the complexity of the die.

The failure rate of products is fairly high for both Spinforming and handforming due to the fact that the operator has to first gain a reasonable idea about the pressures that have to be applied, the revolutions per minute and the feed rate at which the tool should be engaged. The rate at which the operator is able to learn these parameters will determine the degree of products that are successfully made.

In manual forming techniques there are no strict parameters, which the person must abide by. The failures usually occur as cracks in manual forming processes. These are regions where material can no longer undergo further deformation and as such, the material fails. In hand forming of the steel drums, most of the cracks occurred in the central region of the pan. This is primarily because of the stretching and deformation of material.

In some of the spinformed specimens, cracks were also located around the central region. Rubber pad forming techniques produced products with a very high quality. The reject rate for this type of forming is low. Initially there might be problems associated with the formed piece e.g. the formation of wrinkles.

7. Conclusion

Data collection proved to be vital in obtaining critical information pertaining to the different types of forming processes of the steel pan. The graphical representation gave a better overall perspective of the results obtained. The Spinforming and Marforming processes proved to be good methods for prefabricating the steel pan since it enabled thicknesses variations to be attained on wrinkle free products of high quality with fairly low setup times, short production times and long production runs.

The investment capital varies for each of the forming processes. Manual forming techniques require the least capital to engage in production. This might be due to the fact that the forming process only requires the use of simple tools. These may include a hammer, chisel, punch, and other simple hand tools.

The Spinforming technique requires much higher capital than that of the manual method. It usually requires a machine capable of spinning a mandrel at varying speeds. One such machine that can be used is the high-speed lathe. The former might be very expensive and in most cases they come in sets depending upon the application required.

It can be concluded that the Spinforming process is better suited to the manufacture of the steelpan musical instrument for small production runs once experience operators are used. When large quantities of instruments are to be produced, the Marforming process is the preferred method.

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