Thin Wall Machining of Aluminum Alloy: a Review

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Abstract - *Complex thin walled aluminium alloys are widely used in various industries but the most notable industry is the aviation/aerospace industry. In order to reduce the weight of the material and increase the mechanical strength more commingled thin walled parts are being used in the aviation industry. While machining thin walled materials most of the material is removed and it results in large deformation due to weakening rigidity and release of residual stress. Release of residual stress results in stress concentration which would ultimately result in failure of the part. This is one of the major concerns of such kind of materials i.e. its vulnerability to deform very conveniently because of its convoluted structure and reasons discussed above, hence, these materials come under the category of "difficult to machine materials". In this paper various factors would be discussed which leads to high distortion potential of thin walled structures, and address few measures which may perhaps lead to reduction in the predisposition of the thin walled parts to deform.*

Keywords: *deformation, thin walled parts, aluminium, residual stresses, stress concentration, distortion.*

1.0 INTRODUCTION

Aluminium is one of the most ubiquitous metal used in the manufacturing industry because of its unique properties such as light weight, ease of manufacturability, good corrosion resistance and good thermal conductivity. In aviation industry it is one of the most prevalent metal used for manufacturing because of its light weight and good mechanical strength. But in recent times thin wall structured aluminium alloys are becoming more problematic to manufacture because of the problem of deformation, when wall thickness is very low. On the whole, thin wall machining is defined as the machining of thin walls using a specific height to depth ratio (approx. 15:1) and wall thickness (approx. 3-5 mm). To be specific, a thin wall component is where elastic deformation of the wall is larger than or equal to the allowed tolerance requirement(⍰≥T)

Where ⍰= elastic deformation of the wall and T = allowed machining tolerance.

2. CAUSES OF PART DEFORMATION IN THIN WALL MACHINING

2.1 Residual stresses on the material to be manufactured

Residual stresses are that which remains in a bulk that is stationary and at equilibrium with its surroundings in the absence of external forces or thermal gradients and can be categorized to macro stress and micro stress. Residual stresses in engineer usually refer to macro stress. Residual stresses are generated mainly from three resources: mechanical stresses caused by plastic deformation, thermal stresses caused by temperature, and volume stresses caused by phase transformation. Therefore, it is crucial to acknowledge the formation of residual stresses through understanding the thermal-mechanical loading history in various manufacturing stages. Aluminium alloy materials go through several steps in manufacturing, such as casting, rolling, and forging etc. High mechanical and thermal loads during these steps produce residual stresses inside the materials which cause deformation.

2.2 Material and structure of workpiece

The material and structure of the workpiece will affect the deformation of the workpiece. The rate of deformation is proportional to the intricacy of shape, the ratio of length to width and the size of wall thickness, and is proportional to the rigidity and stability of the material. Therefore, the influence of these factors plays a crucial role which induce deformation in the workpiece.

2.3 Deformation caused by cutting force

The workpiece in the cutting process due to the effect of high cutting force, results in high elastic & plastic deformation. Cutting force could become notably high when tools that are being used are not sharp. Therefore, the bluntness of the tool edge would increase the friction between the cutting tool and the workpiece. As a result, the heat dissipation ability of the cutting tool decreases exponentially when cutting the workpiece and thereby augmenting the residual internal stress on the workpiece.

2.4 Heat of friction generated between cutting tool and workpiece

The heat generated by the friction between the cutting tool and the workpiece during machining can also deform the workpiece. Many a times when smaller cutting speeds are employed the chips lose their capability to break of from the workpiece easily. Consequently, due to the inability of chips to break off from the workpiece friction becomes very high at the contact zone as chips are a considerable source of heat dissipation which is generated by friction. In addition to that, if there is no proper use of cutting fluids at contact zone, then heat generated by friction readily deforms the workpiece and the failure of workpiece might occur.

2.5 Stress concentration

An abrupt change in the geometric shape of a part gives rise to additional stress over and above the calculated stress, which is known as stress concentration. For example, if the part to be manufactured has a filleted edge, that corresponding part of the workpiece is a critical point where actual stress is higher than the theoretical stress at this point. Furthermore, if the fillet radius is very small, the change in shape is more abrupt, then the internal stresses do not get enough space to get redistributed evenly, as a result this point act as a critical point which is vulnerable to deform, and consequently resulting in failure of the part to be manufactured.

2.6 Clamping force

When clamping the workpiece, if incorrect clamping point is chosen, then excessive clamping force would act at the corresponding supports. Therefore, if the clamping point and support point are not consistent, clamping force acting on the support would be highly erratic, and the clamping force corresponding to that support would be higher than usual, and therefore that side of the workpiece, which would experience higher clamping force, becomes susceptible to deform and break resulting in failure which is highly undesirable. In addition to that, the material and structure of the workpiece also affect the rate of deformation caused by clamping. Due to the structure of the workpiece one particular surface might have lower rigidity than others, and rigidity is inversely proportional to clamping force. Hence, the face which has low rigidity has a higher chance to get deformed by the clamping force acting on the corresponding support.

3. WAYS TO MINIMIZE PART DEFORMATION IN THIN WALL MACHINING

3.1 Symmetrical machining

For aluminum parts with a large processing allowance, it is necessary to evade an excessive concentration of heat in order to create better heat dissipation and decrease thermal deformation. The method that can be taken to achieve this is called symmetrical processing.

Visualize, for example, that a 100 mm thick aluminum plate needs to be milled to 70 mm thick. If the milling side is immediately turned over to the other side, since each surface is processed to the final size, the continuous processing allowance will be large, which will cause the problem of heat accumulation and the smoothness of the alloy plate will only be able to reach 5 mm.

If the symmetrical processing method of two sides is used repeatedly, nevertheless, each surface can be processed at best two times until the final size is reached, which is good for heat dissipation, and flatness can be regulated at 0.3 mm.

3.2 Multiple machining

When there are several cavities on the aluminum alloy plate parts, it is easy to twist the cavity wall because of the unbalanced forces. The best way to resolve the issue is to take a layered multiple processing method, which is to process all the voids at the same time.

Instead of finishing the part all at the same time, conversely, the part can be divided into several layers and processed to the required size by layer by layer. The force applied to the parts will be more even and the likelihood of deformation will be reduced to a great extent.

3.3 Selecting apposite cutting parameter with respect to multifarious aspects so that it is compatible with the tool and workpiece to be manufactured

Cutting force and subsequent cutting heat can be reduced by choosing proper cutting parameters. In the process of mechanical processing, if the cutting parameters are bigger than normal will leads to excessive cutting force, which can easily cause the deformation of the parts, as well as affecting the rigidity of the spindle and the toughness of the tool.

Among all the factors of cutting parameters, the biggest influence on cutting force is the amount of back cutting depth. But while reducing the number of cutting tools is beneficial to ensure that parts are not deformed, the processing efficiency will also at the same time be reduced.

The high-speed milling of numerical control machining can resolve this problem. By reducing the back-cutting depth, amplifying the feed and improving the speed of the machine, machining can reduce the cutting force and guarantee processing effectiveness.

3.4 Enhancing capability of cutting tools

The material and geometric parameters of cutting tools have an important influence on cutting force and cutting heat. The right choice of cutting tools and parameters is hence very important for reducing the machining distortion of parts.

Geometric parameters of a tool that affects performance:

3.4.1 Front angle

The front angle must be suitably configured to preserve blade strength, or else the sharp edge will become worn out. Appropriately setting the front angle can also reduce cutting deformation, guarantee smooth chip removal and reduce cutting force and cutting temperature. Do not use the negative front angle tool.

3.4.2 Rear angle

The size of the rear angle has a direct effect on both flank wear and machined surface quality, and cutting thickness is an important parameter to consider when configuring the rear angle. When rough milling, the large feed rate, heavy cutting load and large heat mean that the tool must account for heat dissipation. The rear angle should therefore be smaller. In precision milling, however, sharp edges are required to reduce the friction between the flank and the machined surface and reduce elastic deformation. In these cases, the rear corner should be larger.

3.4.3 Helix angle

To make milling stable and reduce milling force, the helix angle should be as large as possible.

3.4.4 Main deflection angle

Suitably reducing the main deflection angle can enhance heat dissipation and reduce the average temperature of the processing area.

3.4.5 Enhance the physical condition of cutting tools

Reducing the number of milling cutter teeth can increase capacity, which can be useful when processing aluminum alloy. Because of the properties of aluminum alloy, cutting distortion is larger, and a large capacity for chip space is needed.

The radius of the tank bottom should be larger and the number of the milling cutter teeth lower. For instance, two cutter teeth are used for the milling cutter below 10 mm, and three cutter teeth are used in the milling cutter of 20 ~ 50 mm to avoid the deformation of thin-walled aluminum alloy parts caused by the blockage of the chip.

3.4.6 Precision grinding cutter teeth

The roughness of the cutting edge of cutter teeth if used should be less than Ra=0.4um. Before using the new knives, use fine oil stones to gently grind the front and rear edges of the teeth to eliminate burrs and slight zigzag patterns. In this way, not only can cutting heat be reduced, cutting deformation can also be minimized.

3.4.7 Precisely controlling tool wear

When tools get worn, workpiece surface roughness increases, cutting temperature increases and workpiece deformation increases. Therefore, along with selecting tool materials with good wear resistance, the tool wear standard should not be greater than 0.2 mm, otherwise built-up nodules can occur. In cutting, the temperature of the workpiece should not exceed 100 degrees to prevent deformation.

3.5 ICONOCLASTIC APPROACHES

Rough cutting and finishing require avant-garde methods while machining of thin walled parts. Rough machining requires cutting the surplus material on the blank surface in the smallest possible time with the fastest cutting speed, forming the geometric contour required for finishing. The importance here is on the processing efficacy and the percentage of material removal happening.

Finish machining, conversely, requires higher machining precision and surface quality. Emphasis should be placed on milling quality. As the cutting thickness of the cutter teeth decreases from the maximum to zero, the machining toughening phenomenon will be greatly reduced and the deformation of the parts can be repressed to a certain extent.

3.6 DUAL COMPRESSION OF THIN-WALLED PARTS

While machining thin-walled aluminum alloy parts, clamping force can cause deformation. In order to decrease the deformation of the workpiece triggered by clamping, the compressed parts should be unclamped before finishing the final dimension, emancipating pressure and reinstating parts to their original shape before reapplying pressure a second time.

The second pressing action point is best on the supporting surface, and the clamping force should be in the direction of utmost rigidity. If everything is correct, the compression force should be able to hold the workpiece without loosening. This method requires an adroit operator, who will ensure that deformation of machined parts machined is curtailed.

3.7 PRE-DRILL AND THEN MILL PARTS WITH A VOID

Machining the parts with a crack presents its particular complications. If the milling cutter is directly applied to parts, cuttings will not be smooth due to the inadequate fragments space of the milling cutter. This leads to the accretion of a great amount of cutting heat, the enlargement and buckling of parts and even possible failure of the part or tool.

The optimal method for dealing with this conundrum is to do pre-drilling and then carry out milling. This includes first drilling the hole with a tool that is no smaller than the milling cutter, and then positioning the milling cutter into the hole to commence the milling procedure.

3.8 BY ENHANCING THE PROCESS STIFFNESS OF THIN-WALLED PARTS

In the numerical control milling of thin-walled parts, augmenting the stiffness and robustness of thin-walled parts can efficiently enhance the stress resistance of thin-walled parts, thus minimizing the deformation of the processing and the distortion of the machining. The methods to boost the strength of thin-walled parts are as follows:

i) using a fluid, spraying, etc in the inside of the workpiece with some easily removable materials, in so doing reinforcing the wall thickness of the part and enhancing the rigidity.

ii) using a higher modulus of elasticity, the material can effectively bolster the rigidity of the part and circumvent the deformation of the force.

iii)Because the process rigidity of the thin-walled part is related to the processing method, the actual machining precision and surface flatness between the tool and the workpiece can be improved, thereby improving the contact rigidity, thereby buttress the stiffness of the material.

3.9 HIGH-SPEED MACHINING OF THIN-WALLED PARTS

The benefit of high-speed milling of thin-walled parts is that the cutting force is insignificant, so the distortion of the workpiece instigated by the workpiece is reduced significantly when processing thin-walled parts, and it is convenient to ensure the dimensional precision and shape exactness of the parts; When the chip is taken away, the temperature of the workpiece is not high, and the thermal deformation of the workpiece is inconsequential, which is very beneficial for reducing the deformation of the thin-walled part; the excitation rate of recurrence of the tool is amplified to circumvent the excitation frequency, and hence side-stepping the vibration frequency range of the thin-wall assembly process system. In so doing, evading cutting vibration and attaining even cutting; the tool has short elongation and good rigidity. It can be seen above that high-speed machining does have substantial advantages.

4. CONCLUSION

In this paper various practical concerns regarding the manufacturing of aluminium alloy with thin wall thickness were discussed. Reasons for the vulnerability of such workpiece to deform readily were explored. Finally, the paper concluded by addressing countermeasures which could be taken to reduce the rate of deformation caused by various factors which were scrutinized in detail previously. More sophisticated approaches might still be needed to optimize the parameters while machining aluminium alloy with very low wall thickness(3-5mm).

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