BURR FORMATION IN ALUMINUM AND STEEL HOLES DRILLED BY A BENCH DRILL WITH A SPINDLE-MOUNTED SPRING

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ABSTRACT

Modern industrial operations wouldn't accept old defects to be present in the new products, especially that many products include electronic parts or connections that are very sensitive to the level of finish. Burr formation in drilling operations causes products to be rejected or sent for deburring. Since deburring is a costly and non-value-added operation, the understanding and control of burr formation is a research topic with high relevance to industrial applications. In order to investigate and improve burr formation, a spring was mounted over the bench drill spindle to measure the cutting force and attempt to know its influence on the burr outcome of the operation.

Keywords: burr, formation, drilling process

1. Introduction

The demands placed by designers on workpiece performance and functionality are increasing rapidly. Important aspects of manufacturing’s contribution to the fulfillment of these demands are the conditions at the workpiece edges[1]. The presence of burrs on the edges of parts after machining, which may bring about a number of problems, makes deburring a necessary part of the production process. The proper way of burr removal, the conditions of deburring, and the deburring cost depend on the part’s features and the burr dimensions [2]. Not only deburring is a non-value-added process, but in many cases increasing burr formation is a key factor of cutting tool wear and leads to replacement of tools. Burrs do not have to be removed from a workpiece for functional reasons, there are still two dangers remaining. Firstly, burrs are often quite sharp and can lead to small finger injuries for assembly workers. Secondly, burrs which initially stick to a part can become loose during operation of a product and cause damage later on.

In conventional drilling, burr formation can be changed by varying the drill’s geometry [3]. Its formation is due to a plastic deformation on a ductile material. This imperfection can be formed at the entrance as at the exit of a hole, although its appearance is more common on the last one.

1.1. Burr descriptions and classification

Presently, there are various international and national standards as well as proprietary standards for describing burrs and evaluating the quality of component edges.

For thousands of years there was no word for a ‘‘burr’’ formed by machining, but Erasmus Darwin, grandfather of Charles Darwin, a naturalist and poet, appears to be the first person to mention ‘‘burr’’ in writing (1784).

In the Oxford English Dictionary a burr is described as a rough ridge or edge left on metal or other substance after cutting, punching, etc.; e.g. the roughness produced on a

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copper-plate by the graver; the rough neck left on a bullet in casting; the ridge left on paper, etc., by puncture [1].

1.2. Burr definitions

The ISO 13715 defines the edge of a workpiece as burred if it has an overhang greater than zero. Schaefer [4] gives one of the earliest technical descriptions of a burr. He describes a burr as the part of a workpiece which is produced through manufacturing processes on an edge or a surface and which lies outside the desired geometry.

Ko and Dornfeld[5] bases his work on this definition and defines a burr as an ‘‘undesirable projection of material formed as the result of plastic flow from a cutting or shearing operation’’.

A comprehensive definition can be found in [6]. A burr is a body created on a workpiece surface during the manufacturing of a workpiece, which extends over the intended and actual workpiece surface and has a slight volume in comparison with the workpiece, undesired, but to some extent, unavoidable.

1.3. Types of burrs in material removal

Today, there exist numerous different burr descriptions depending on application, manufacturing process, shape, formation mechanism and material properties [1].

Gillespie and Blotter [7] is among the first to describe different types of burrs. Four types of machining burrs were detected: Poisson burr, rollover burr, tear burr and cut-off burr, as shown in Fig. 1.

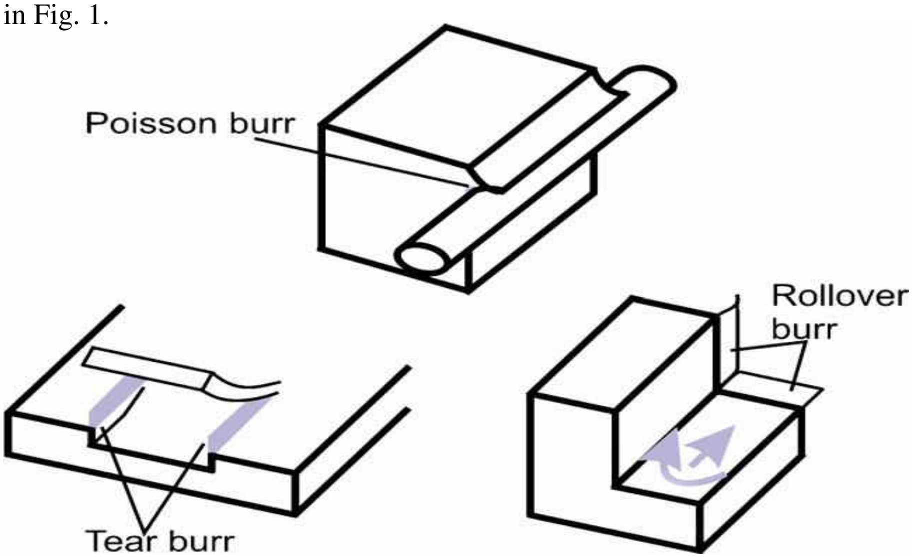

Fig. 1. Schematic of Poisson, tear and rollover burr

In drilling, the burr that forms at the entrance of the hole can be a result of tearing, a bending action followed by clean shearing, or lateral extrusion. The burr that is formed when a sharp drill exits the workpiece is a Poisson burr resulting from rubbing at the margins of the drill. When a normal or worn out drill exits the uncut chip rolls, resulting in a rollover burr [8].

Kim et al[9] categorize drilling burrs as uniform burr with or without a drill cap, crown burr or petal burr according to their shapes and formation mechanism. Two types of burrs, uniform burr (type I: small uniform burr, type II: large uniform burr) and crown burr, for stainless steel and three types of burrs, uniform burr (type I: small uniform burr, type II: large uniform burr), transient burr, and crown burr, for low alloyed steel were found as shown in (Fig. 2).

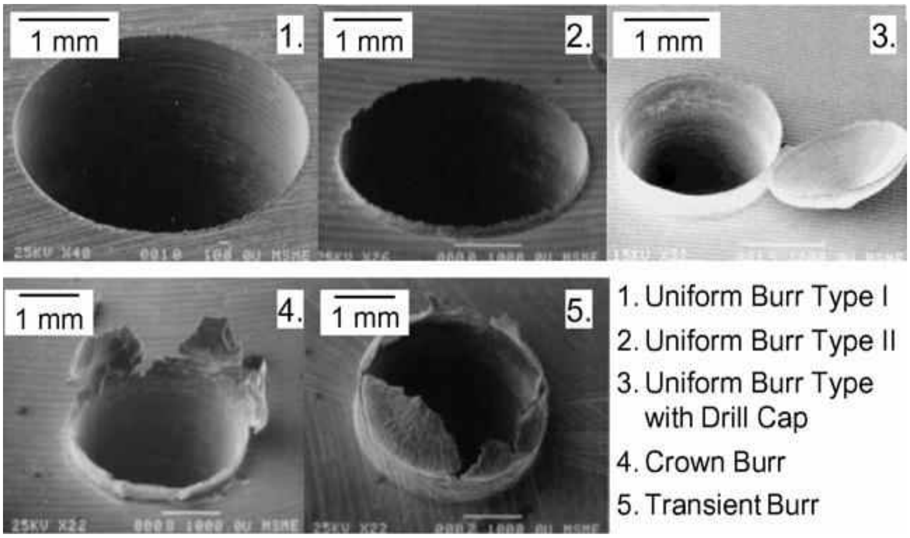

Fig. 2. Typical drilling burr types according to CODEF

2. Parameters that influence burr formation

It is necessary to differentiate investigations which cover burr form and others that cover the topic of minimizing burrs. Gillespie and Blotter [7] already observe that burrs cannot be prevented by changes in feed, speed, or tool geometry alone. Still, the size of burrs produced can be minimized significantly by choosing appropriate machining parameters. To minimize and prevent burrs it is necessary to examine the entire cutting process. It is not sufficient to change only one process parameter as there are many influences between the parameters. Burr formation is affected by various parameters. Major effects are workpiece material, tool geometry, tool wear, tool path and machining parameters. In most cases a change of workpiece material is not possible. As to an improved tool path, this approach is also limited, as complex geometries would require burr optimized tool paths that prolong cycle time as negative effect.

Link [10] points out that burr formation parameters cannot reliably be separated into direct and indirect factors due to the complex connections and relations between the numerous influencing variables (Fig. 3). Wang and Zhang [11] investigate cutting burrs.

The main factors of cutting direction burr formation are cutting parameters, the shape of the workpiece end, cutting tool geometry and workpiece material. The burr height in cutting direction is reduced with the increase in the depth of cut, feed, cutting edge angle and back rake angle. An increase of corner radius leads to increasing burr height.

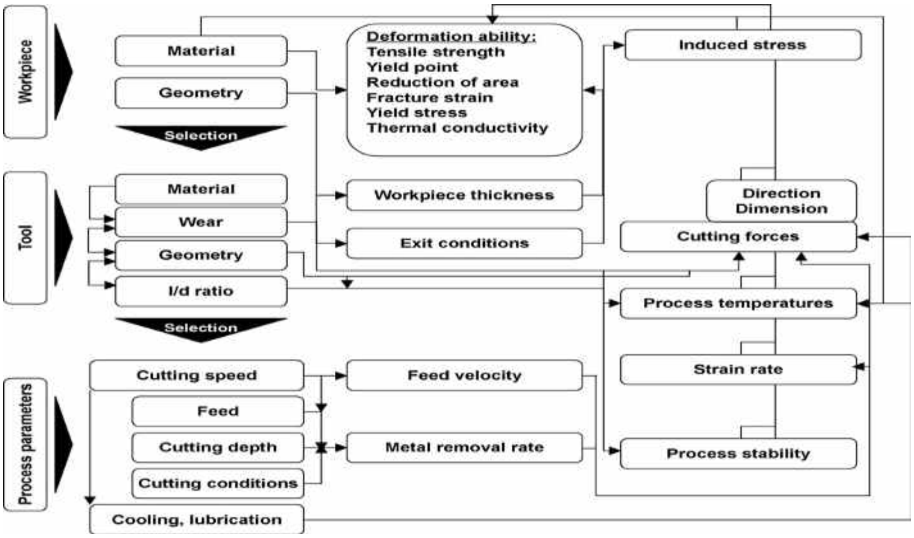

Fig. 3. Interdependencies of burr formation parameters

3. Scope of previous studies

The above mentioned parameters were studied by numerous researchers, each focusing on a single or a group of parameters.

Dornfeld et al [12], studied the effects of tool geometry as well as process conditions on the drilling burr formation for Titanium alloy (Ti-6AI-4V) plates. Drilling was done with solid carbide tools with and without coolant and high speed cobalt drills without coolant. Four distinct burr types were observed. During dry cutting, a “rolled back” type burr was observed at high feed rates and cutting speeds and is believed to be due to thermal effects. A “ring” type burr was observed when drilling with coolant. While cutting conditions had little effect on the burr sizes formed, drill geometry (helix angle, split point vs. helical point, lip relief angle and point angle) affected burr thickness and height.

Stein & Dornfeld [13] studied the exit burrs in the drilling of precision miniature holes. They reported on the study of burr height, thickness and geometry observed in the drilling of 0.91 mm diameter through holes in stainless steel 304L. The sensitivity of feed, speed and drill wear as well as the exit surface geometry (i.e. for intersecting holes) was determined. A proposal for using the drilling burr data as part of a process planning methodology for burr control was presented.

Lo and Lee [14] studied a concept drill developed for increasing productivity and accuracy in the drilling operation. They have classified burr into three types according to the location of crack. To observe the burr formation mechanism, they measured the cap formed.

Saunders [15], presented a finite element model to address the limitations of classical models of burr formation in drilling. In this model, 2D analysis was used to predict the temperature distribution and stress state in the workpiece. Material removal was simulated through the use of element death and continued until a failure condition was predicted. At the point of failure, the remaining material is bent out to form the burr. The FEA model was compared with previous "classical" models as well as experimental data for 2024 aluminum.

In addition to the above, there are other studies that have studied the various aspects influencing burr formation, shapes, minimization, materials, operations, etc. Each paper called for more detailed work on such issues.

4. Results and Discussion

Burr studies are still new to the Egyptian industrial operations. The economic losses caused by such defect are not yet determined. The conditions having influence on burr are not fully explored. Such parameters include the skill of operators, and the overall atmosphere of the operation. In our study, burr formation in drilling operations is studied with a spring being introduced to control the drilling force. The material used is aluminum. The machine is a bench drill widely used in workshops. The spring is used to control the drilling force and, hence, study the effect of this technique on the formation of burr. Force is an important parameter that needs to be measured to investigate its influence on burr formation. Thickness of the material used is 4mm.

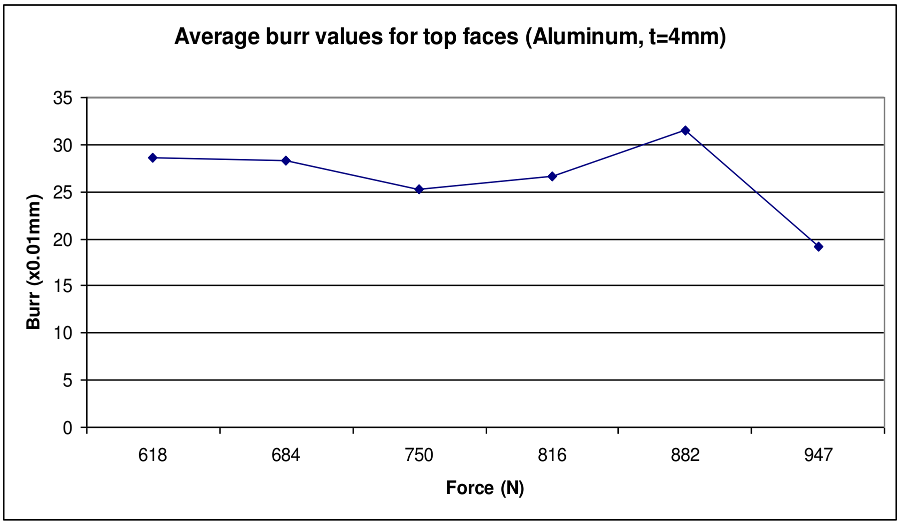

Fig. 4. Average burr values for the top faces (t=4mm)

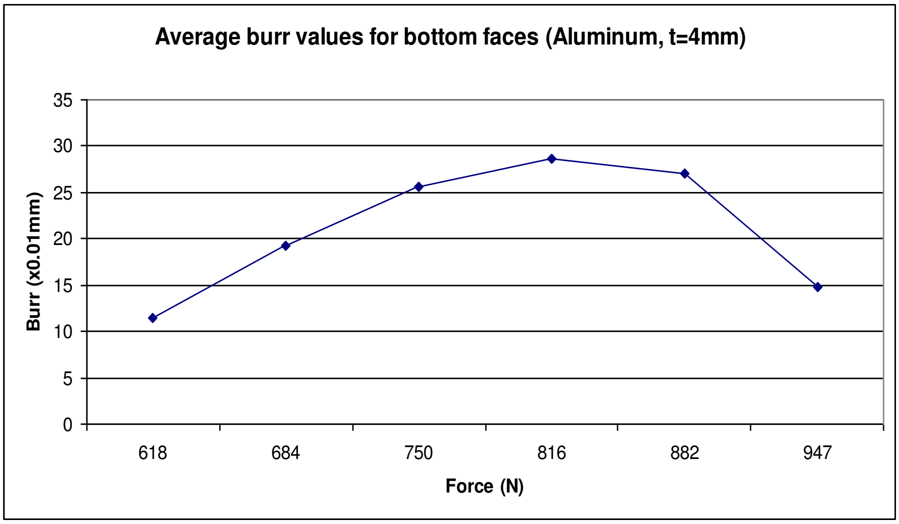

Fig. 5. Average burr values for the bottom faces (t=4mm)

5. Interpretation of results

5.1. Top faces

Fig. 4 shows the variation of burr height at different values of the applied forces for the top faces.

1- For force of 618 N (x=47mm), burr measurements showed varying values with $15.83*10^{-2}$mm being minimum and $61.50*10^{-2}$mm as maximum.
2- For force of 684 N (x = 52.05mm), there was less variance with a minimum value of $10.17*10^{-2}$mm and a maximum of $46.5*10^{-2}$mm.
3- For force of 750 N(x= 62mm), the minimum burr was $11.67*10^{-2}$mm, and the maximum was $65.33*10^{-2}$mm.
4- For force of 816 N (x= 67mm), the minimum burr was $12.83*10^{-2}$mm with a maximum of $45.33*10^{-2}$mm.
5- For force of 882N (x=72mm), the minimum burr was $11.00*10^{-2}$mm and the maximum $56.67*10^{-2}$mm.
6- For force of 947N (x=77mm), the minimum burr value was $12.50*10^{-2}$mm and the maximum $32.67*10^{-2}$mm.

The lowest burr average was obtained for the sixth force $19.23*10^{-2}$mm and the highest value was $31.51*10^{-2}$mm for the fifth force.

The difference between the highest and lowest burr values was maximal for the third force, and minimal for the sixth force.

From fig.4, it is clear that

Burr values showed a slight decrease till 750N, and then increased towards a maximum at the 882N. After 882 N a sharp decline can be seen. This would indicate the fifth force (882 N, x=72) as a critical peak. Abnormal burr values could be attributed to the following:-

1. Human errors: adjusting errors, measuring errors.
2. Material-specific errors: differences in material density, non-homogeneity of some samples.
3. Machine related errors: electricity fluctuations leading to rpm changes, wear of drill, etc.

5.2. Bottom faces

Fig. 5 shows the variation of burr length at different values of the applied forces for the bottom faces.

1. For force of 618 N (x = 47.82), the minimum burr value was 7.17*10-2mm, with a maximum of 14*10-2mm.
2. For force of 684N (x = 52.05), the minimum burr value was 11.33*10-2mm, and the maximum was 40.67*10-2mm.
3. For force of 750N (x= 62), the minimum burr value was 11.17*10-2mm, and maximum was 36.5*10-2mm.
4. For force of 816N (x=67), the minimum burr value was 16.5*10-2mm, and the maximum was 43.5*10-2mm.
5. For force of 882N (x=72), the minimum burr value was 14.33*10-2mm, and the maximum was 42.33*10-2mm.
6. For force of 947N (x=77), the minimum burr value was 8.5*10-2mm, and the maximum was 34.17*10-2mm.

The lowest burr average was obtained for force of 618N ($11.53*10^{-2}$mm), and the highest was obtained for force of 816N ($28.59*10^{-2}$mm) followed by force of 882N ($27.08*10^{-2}$mm).

The difference between the lowest and highest values was maximal for the force of 816N and minimal for the force of 618N.

From fig.5, it is clear that:

Burr values showed a gradual increase to a maximum at the force of 816N and then decreased towards the force of 947 N. This indicates the (816-882N) span as being critical, as was noticed for the top faces. Variance in values is less for the bottom faces. This appears to be normal due to the mechanics of the process of drilling. Abnormal values are not as high as those for the top faces. The highest value obtained was $43.5*10^{-2}$mm which is much less than the highest value obtained in the top faces ($65.33*10^{-2}$mm). The average value of all top faces samples is $26.58*10^{-2}$mm, with a value of $21.12*10^{-2}$mm for the bottom faces. This means a reduction of 21.55% in the average.

Results indicate that the(816-882N) force range is critical for both faces. A decline in the burr value occurs starting from this range. Before reaching this range, an increase in the burr values is detected with slight variations.

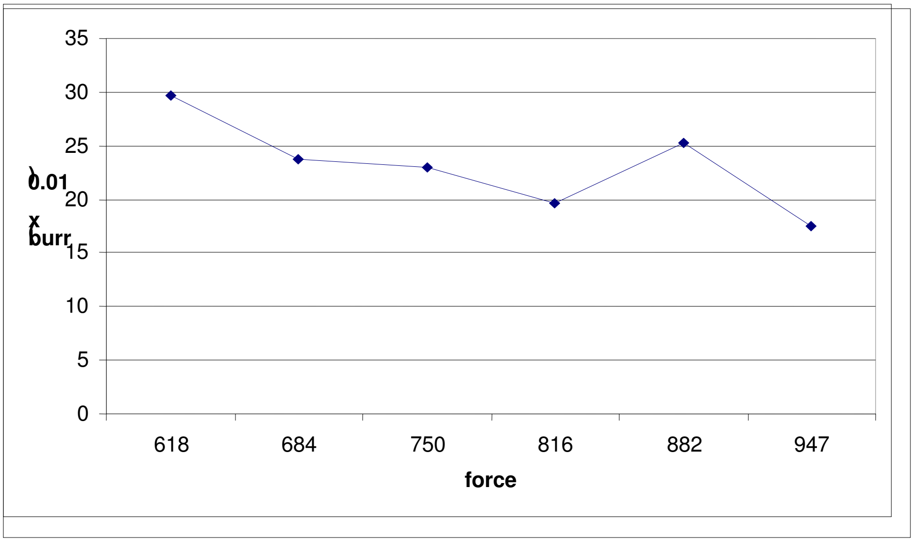

Fig.6. Average burr values for top faces (t=7mm)

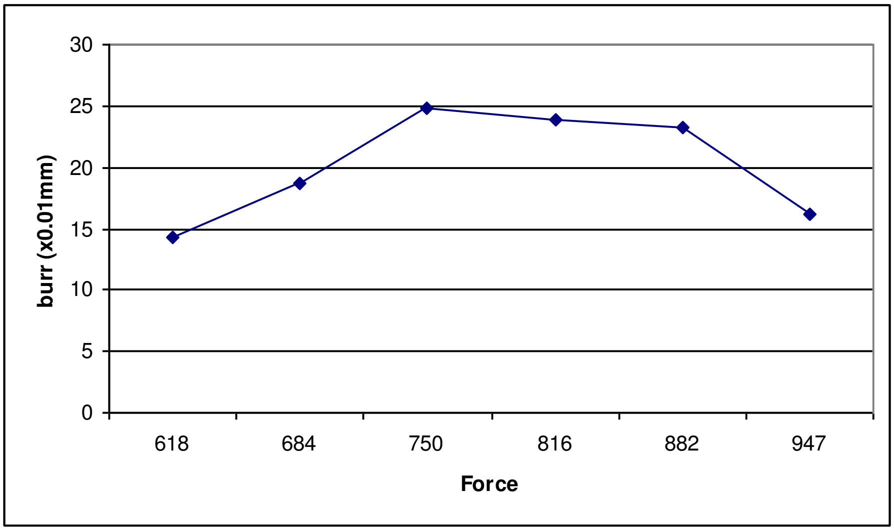

Fig.7. Average burr values for bottom faces (t=7mm)

6. Interpretation of results

6.1. Top faces

Fig. 6 shows the variation of burr height at different values of the applied forces for the top faces.

1. For the force of 618N (x= 47.82) burr measurements showed varying values with 16.50*10-2mm being minimum and 62.50*10-2mm as maximum.
2. For the force of 684N (x = 52.05) there was less variance with a minimum value of 11.17*10-2mm and a maximum of 37.17*10-2mm.
3. For the force of 750N (x= 62) the minimum burr was 10.83*10-2mm, and the maximum was 48.17*10-2mm.
4. For the force of 816N (x= 67), the minimum burr was 11.67*10-2mm with a maximum of 39.17*10-2mm.
5. For the force of 882N (x=72), the minimum burr was 13.17*10-2mm and the maximum 36.50*10-2mm.
6. For the force of 947N (x=77), the minimum burr value was 4.83*10-2mm and the maximum 33.17*10-2mm.

The lowest burr average was obtained for the force of 947N ($4.83*10^{-2}$mm) and the highest value was ($62.50*10^{-2}$mm) for the force of 618N.

The difference between the highest and lowest burr values was maximal for the force of 618N, and minimal for the force of 882N.

From fig.6, it is clear that

Average burr values for the top faces (t=7mm) were shown in fig.6. Burr decreased continually till the fourth force, and then increased towards a maximum at the force of 882N. After the force of 882N, a sharp decline can be seen. This would indicate the force of 882N (x=72) as a critical peak. In general variation of values is less than the previous thickness. Yet, abnormal burr values could be attributed to the following:-

1. Human errors: adjusting errors, measuring errors.
2. Material-specific errors: differences in material density, non-homogeneity of some samples.
3. Machine related errors: electricity fluctuations leading to rpm changes, wear of drill, etc.

6.2. Bottom faces

Fig. 7 shows the variation of burr height at different values of the applied forces for the bottom faces.

1. For the force of 618N (x = 47.82mm), the minimum burr value was 11.33*10-2mm, with a maximum of 20*10-2mm.
2. For the force of 684N (x = 52.05mm), the minimum burr value was 12.83*10-2mm, and the maximum was 36.50*10-2mm.
3. For the force of 750N (x= 62mm), the minimum burr value was 10.83*10-2mm, and maximum was 48.17*10-2mm.

4. For the force of 816N (x=67mm), the minimum burr value was 14.83*10-2mm, and the maximum was 39.17*10-2mm.
5. For the force of 882N (x=72mm), the minimum burr value was 13.17*10-2mm, and the maximum was 34.33*10-2mm.
6. For the force of 947N (x=77mm), the minimum burr value was 8.83*10-2mm, and the maximum was 33.17*10-2mm.
7. The lowest burr average was obtained for the force of 947N (8.83*10-2mm), and the highest was obtained for the force of 750N (48.17*10-2mm).
8. The difference between the lowest and highest values was maximal for the force of 750N and minimal for the force of 618N.

From fig.7, it is clear that burr values showed a gradual increase to a maximum at the force of 750N, and then decreased towards the force of 947N. This indicates the750-882N force span as being critical. Variance in values is less for the bottom faces. This appears to be normal due to the mechanics of the process of drilling. Abnormal values are not as high as those for the top faces. The highest value obtained was $48.17*10^{-2}$mm, much less than the highest value obtained in the top faces ($62.50*10^{-2}$mm). The average value of all top faces samples is $29.73*10^{-2}$mm, with a value of $20.16*10^{-2}$mm for the bottom faces. This means a reduction of 32.2% in the average.

Results indicate that the 816-882N force range is critical for both faces. A decline in the burr value occurs starting from this range. Before reaching this range, patterns of burr vary between the top and the bottom.

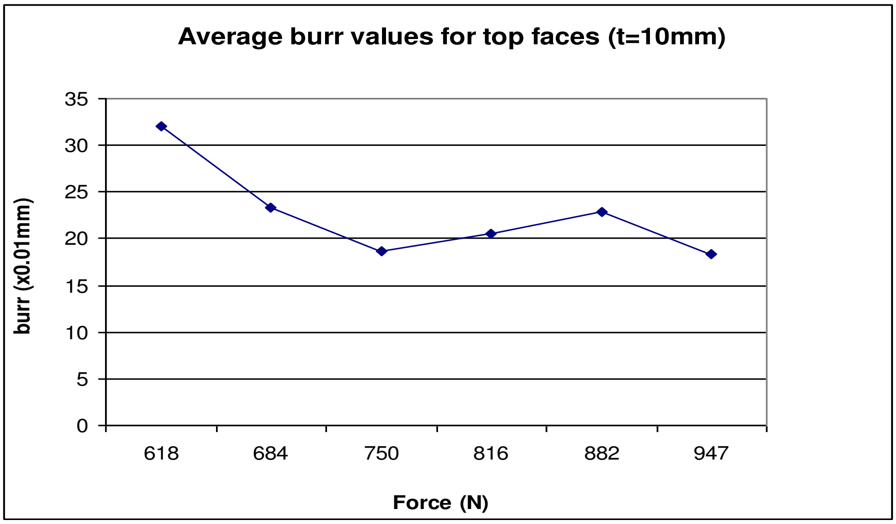

Fig.8. Average burr values for the top faces (t=10mm)

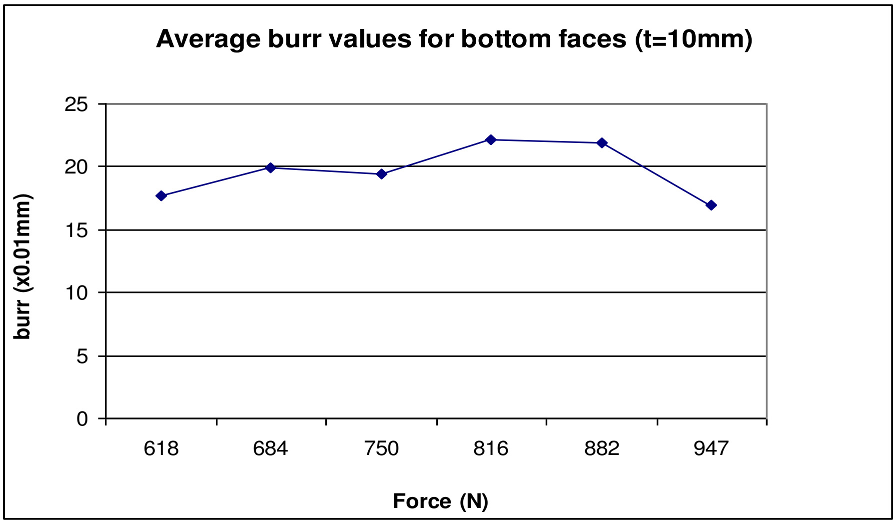

Fig.9. Average burr values for the bottom faces (t=10mm)

7. Interpretation of results

7.1. Top faces

Fig. 8 shows the variation of burr length at different values of the applied forces for the top faces.

For the force of 618N: (x= 47.82mm) burr measurements showed strongly varying values with $20.17*10^{-2}$mm being minimum and $96.5*10^{-2}$mm as maximum.

For the force of: 684N (x = 52.05mm) there was more variance with a minimum value of $13.83*10^{-2}$mm and a maximum of $35.50*10^{-2}$mm.

For the force of 750N (x= 62mm) the minimum burr was $13.00*10^{-2}$mm, and the maximum was $30.50*10^{-2}$mm.

For the force of 816N (x= 67mm), the minimum burr was $13.50*10^{-2}$mm with a maximum of $33.50*10^{-2}$mm.

For the force of 882N (x=72mm), the minimum burr was $16.67*10^{-2}$mm and the maximum $29.17*10^{-2}$mm.

For the force of 947N (x=77mm), the minimum burr value was 10.33 and the maximum 25.67.

The lowest burr average was obtained for the force of 947N ($10.33*10^{-2}$mm) and the highest value was ($96.5*10^{-2}$mm) for 618N the force of .

The difference between the highest and lowest burr values was maximal for the force of 618N, and minimal for the force of 882N.

Fig. 8 shows that burr decreased sharply till the force of 750N, and then increased towards a maximum at the 882N. After the force of 882N, a decline can be seen. This would indicate the force of (882N, x=72mm) as a critical peak. In general variation of values is more than the previous thickness. Yet, abnormal burr values could be attributed to the following:-

1. Human errors: adjusting errors, measuring errors.
2. Material-specific errors: differences in material density, non-homogeneity of some samples.
3. Machine related errors: electricity fluctuations leading to rpm changes, wear of drill, etc.

7.2. Bottom faces

1. For the force of 618N (x= 47.82mm) burr measurements showed slightly varying values with 14.50*10-2mm being minimum and 22.50*10-2mm as maximum.
2. For the force of 684N (x = 52.05mm) there was more variance with a minimum value of 14.50*10-2mm and a maximum of 28.83*10-2mm.
3. For the force of 750N (x= 62mm) the minimum burr was 13.17*10-2mm, and the maximum was 29.00*10-2mm.
4. For the force of 816N (x= 67mm), the minimum burr was 16.67*10-2mm with a maximum of 29.33*10-2mm.
5. For the force of 882N (x=72mm), the minimum burr was 14.50*10-2mm and the maximum 32.67*10-2mm.
6. For the force of 947N (x=77mm), the minimum burr value was 12.17*10-2mm and the maximum 27.33*10-2mm.
7. The lowest burr average was obtained for the force of 947N (12.17*10-2mm) and the highest value was (32.67*10-2mm) for the force of 882N.
8. The difference between the highest and lowest burr values was maximal for the force of 882N, and minimal for the force of 618N.

8. Interpretation

Burr increased slightly till the684-750N force span, and then increased towards a maximum at the 816-882N force span. After the force of 882N, a sharp decline can be seen. This would indicate the 816-882N force span as a critical peak. In general variation of values is less than the previous thickness. Yet, abnormal burr values could be attributed to the following:-

1. Human errors: adjusting errors, measuring errors.
2. Material-specific errors: differences in material density, non-homogeneity of some samples.
3. Machine related errors: electricity fluctuations leading to rpm changes, wear of drill, etc.

Results indicate that the 816-882N force range is critical for both faces. A decline in the burr value occurs starting after this range. Before reaching this range, patterns of burr vary between the top and the bottom. Abnormal values are not as high as those for the top faces. The highest value obtained was $32.67*10^{-2}$mm, much less than the highest value obtained in the top faces ($96.50*10^{-2}$mm). The average value of all top faces samples is $22.64*10^{-}$

^{2}mm, with a value of 19.66*10^{-2}mm for the bottom faces. This means a reduction of 13.2% in the average, which is the closest value between top and bottom faces for the three thicknesses used.

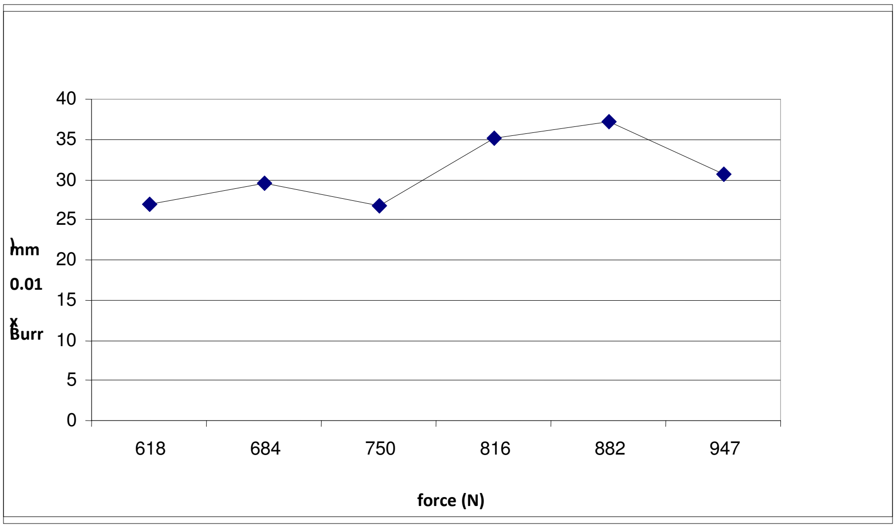

Fig 10. Average burr values for top faces (steel)

8.1. Top faces

All diagrams of the six forces show irregular patterns of burr. Again this could be due to:-

1. Human errors: adjusting errors, measuring errors.
2. Material-specific errors: differences in material density, non-homogeneity of some samples.
3. Machine related errors: electricity fluctuations leading to rpm changes, wear of drill, etc.
4. The burr values per forces diagram show a less irregular pattern. Again, the force 882N proves to be critical as was the case for aluminum samples.

8.2. Bottom faces

1. As for the top faces, irregular patterns prevail for each force diagram, yet in a less sharp manner. The same possible causes apply as is the case for the top faces.
2. The burr values per forces diagram shows equal average values up to 882N. Again this force appears as a critical one, as the curve goes up after 882N.

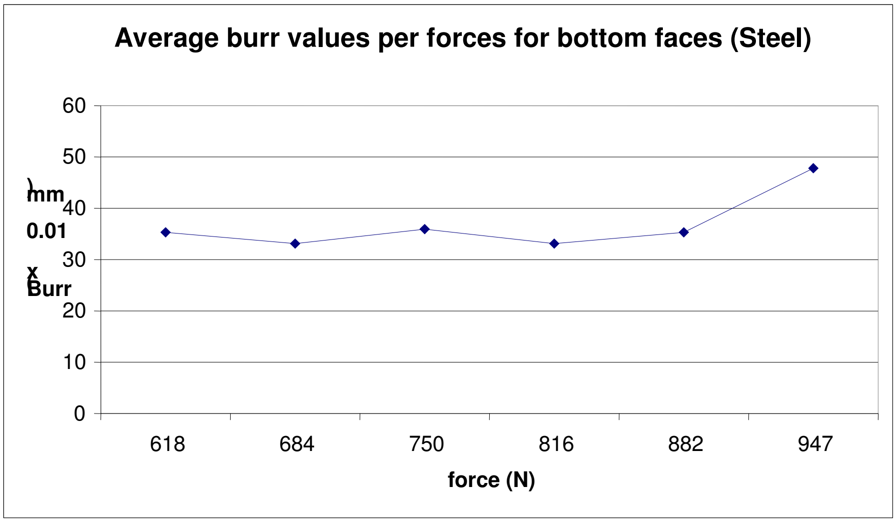

Fig 11. Average burr values for top faces (steel)

9. Comparison of steel and aluminum

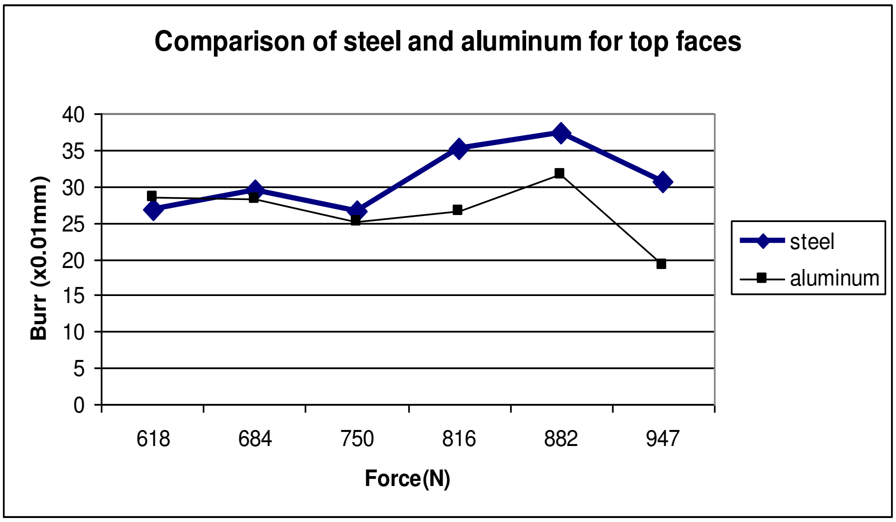

Fig. 12. Comparison of steel and aluminum for top faces

1. The overall average burr is higher for steel (31.025*10-2mm vs 26.586*10-2mm).
2. Average burr values per forces are close for the span 618-750N. Starting from 816N, steel tends to have much higher burr values. Both metals have critical peaks at 882N, and then start to fall – with a sharper decline for aluminum. This could be

due to the harder surface of steel, which makes penetration more difficult. The first half of the force span seems to be equally tolerable by both metals. The second half declares steel as a harder metal.

9.1. Bottom faces

From fig.13, it is clear that:

1. The overall average burr is much higher for steel (36.74*10-2mm vs 21.12*10-2mm).
2. Average burr values are much higher for steel. The patterns are reversed, with 882N as a critical peak for both metals: rise for steel, and fall for aluminum. This is another evidence for the behavior of both metals based on their hardness (and other microstructure properties). Such properties need to be considered in future results for a more accurate explanation of experimental findings.

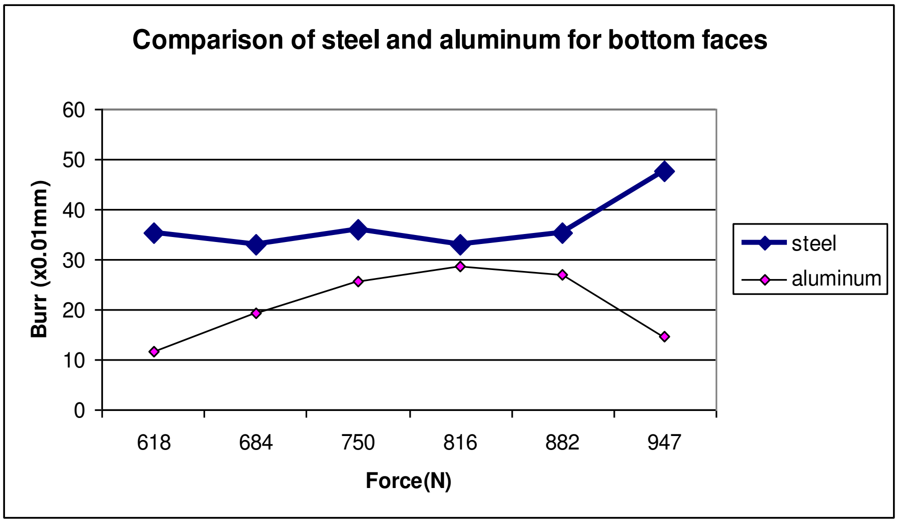

Fig. 13. Comparison of steel and aluminum for bottom faces

10. Conclusions

More work could be performed for investigating the influence of changing spindle compression on reducing burr. This technique needs more elaborate lengthy experiments for establishing precise relationships between spring compression and burr formation. Finding optimized spring compression is something dependent on the workpiece material, thickness, as well as other factors that may be included in future experiments. With extensive experiments, an optimization trend could be established for the force-thickness patterns of aluminum/steel and other materials used in industrial applications.

11. References

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دراسة النتوءات للثقوب باستخدام عمود إدارة مضغوط

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ملخص:

عمليات إزالة النتوءات تكون مكلفة ومستهلكة للوقت. وبسبب الأهمية الخاصة التي تتمتع بها عملية الثقب في الصناعة، يجب البحث عن طرق لتقليل تلك النتوءات من أجل تقديم ثقوب نظيفة سليمة ملائمة للتطبيقات المختلفة في الصناعة. ولهذا تبحث هذه الدراسة الإجابة عن الأسئلة التالية:

1. هل ستؤدي زيادة انضغاط الزنبرك على عمود المثقاب إلى تحسين نتائج النتوءات؟
2. كم سيكون مقدار اختلاف النتوءات مع مختلف أسماك الشغلة؟

جاءت أعمال هذا البحث لتحاول الإجابة على الأسئلة السابقة، مع هدف أسمى هو تقليل أحجام النتوءات بشكل كبير عند ثقب ألواح المعدن. ولذلك فقد وضعت الأهداف التالية:

1. إجراء تجارب لتحديد العلاقة بين حجم نتوءات الثقب وانضغاط العمود وسمك الشغلة.
2. تحديد أنماط النتوءات- القوة/السمك بالنسبة للألومنيوم والصلب المستخدمين في البحث.

هيكل الرسالة

الفصل الثاني يعطينا معلومات تفصيلية عن عملية الثقب وتكون النتوءات مع استعراض الأبحاث السابقة ذات الصلة بالأهداف البحثية سالفة الذكر. الفصل الثالث يصف التجارب التي تم إجراؤها لدراسة تكون النتوءات في عملية الثقب مع ذكر المعاملات الواردة في التجارب. الفصل الرابع يصف العمل المنجز والنتائج لكل تجربة مع تفسير النتائج الواردة حسب الرسومات البيانية والأرقام الناتجة. الفصل الخامس يلخص أهم ما تم التوصل إليه في هذه الرسالة ويقدم توصيات للأبحاث المستقبلية الممكن إجراؤها في هذا الموضوع.