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HOLE FINISH CONTROL IN 4330.
VANADIUM MODIFIED STEEL

PDO 6989152, Final Report

D. A. Mitchell, Project Leader

Internal Distribution March 1973

Prepared for the
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**Kansas City
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Project Leader:
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Department 821

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Key

HOLE FINISH CONTROL IN 4330 VANADIUM MODIFIED STEEL

BDX-613-863, UNCLASSIFIED Final Report, Internal Distribution March 1973

Prepared by D. A. Mitchell, D/821, under PDO 6989152

Holes 0.312 (7.938 mm) inch to 0.500 inch (12.700 mm) in diameter with a 16 microinch (406.4 nm) AA surface finish and a 0.0003 inch (7.62 μ m) hole tolerance can now be machined in 4330 vanadium modified steel. This will allow part assembly with press fit pins. "Ballizing" and jig grinding were the best of six methods. Ballizing was determined to be sensitive to initial hole size, finish, and shape; ball size and finish; and lubrication used. Jig grinding produced better hole sizes and finishes than ballizing, but was more time consuming.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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SUMMARY

Bendix has developed two methods of producing a 16 microinch (406.4 nm) AA finish hole with a 0.0003 inch (7.62 μm) hole tolerance in parts made of 4330 vanadium modified steel.

The parts, manufactured by Bendix under paid orders from Lawrence Livermore Laboratory (LLL), require holes with these tight tolerances to allow detail parts to be assembled with press fit pins. Classified as an ultra-high-strength steel, 4330 vanadium modified steel is readily machined in its annealed condition. However, for this project the steel must be heat treated to Rc 38 to 42; this hardness, combined with the toughness of the materials, makes it more difficult to produce a hole of the required finish and tolerance.

The methods investigated included reaming, boring, burnishing, "ballizing," and jig grinding; ballizing and jig grinding were found superior. Ballizing required more evaluation of its variables than did the others. Jig grinding with a mounted grinding stone produced a better hole size and finish than ballizing but required too much time. Substitution of a carbide rotary burr tool shortened the machine time by half while maintaining the surface finish and hole size within design requirements, but the process was still slower than ballizing.

To successfully produce the desired hole size and finish, inspection methods will have to be standardized.

DISCUSSION

SCOPE AND PURPOSE

Because of an off-schedule order requirement from LLL, Bendix had to develop a method for fabricating and finishing critical holes to meet design requirements.

ACTIVITY

The 4330 vanadium modified steel is classified as an ultra-high-strength steel. The machinability information states that this material is readily machined in annealed condition. However, the material on this project was required to be heat treated to Rc 38 to 42 hardness. The material, therefore, presented a difficult problem for the hole finishing operation. The paid orders required that Bendix fabricate parts and provide holes in these parts that would allow the detail parts to be assembled with press fit pins. Each assembly required four hole patterns, with each pattern to be one of three sizes: 0.312 inch (7.938 mm), 0.375 inch (9.51 mm), or 0.500 inch (12.7 mm) in diameter. Only the 0.500 diameter holes were through holes; the blind holes had to be finished within 0.010 inch (0.25 mm) of the bottom, and the bottom of the hole had to be within 0.020 inch (0.5 mm) of the far surface.

To achieve the LLL requirements, these alternatives were selected as possible processes for manufacturing the holes:

- Drill and ream;
- Drill and bore;
- Drill, ream, and lap;
- Drill, bore, and roller burnish;
- Drill, bore, and ballize; and
- Drill, ream, and jig grind.

The first two methods were quickly eliminated from the list of alternatives because neither hole size or finish could be satisfied. The surface finish from drilling and reaming ranged from 80 to 130 microinches (2 to 3.3 μm) AA as measured with a Brush surface finish analyzer. Tear marks were evident in the holes, and variations in speeds, feeds and coolants did not significantly improve the finish.

The drilling, reaming, and lapping did improve the hole finish as expected, but the size and geometry of the hole suffered. This alternative proved to be slow and, regardless of parameter settings, resulted in an imperfect hole that was bellmouthed tapered, or larger in the middle. This condition could not be reduced to an acceptable limit; therefore, lapping was found to be unacceptable with existing equipment.

Roller burnishing improved the finish considerably over reaming or boring. But the geometry of the hole proved to be the downfall of this technique. In all hole sizes, roller burnishing left a bellmouthed hole which could not be eliminated. Also, because the holes were not always perpendicular to the parent material surface, the tool tended to stray and result in out-of-round holes. This condition was caused by the rollers engaging one side of the hole first: the resultant pressure pushed the tool to one side. Because the pressure was not equal until all rollers were below the surface, an out-of-round condition was created. An attempt to guide the burnishing tool into the hole did not prove successful.

The ballizing technique resulted in satisfactory holes, but required more evaluation of parameters than any other method. This technique was found sensitive to these conditions:

- Amount of parent material left for the ballizing operation;
- Hole finish before ballizing;
- Ball size relative to finish size;
- Surface finish of the ball; and
- Lubricant used in the operation.

The hole size, finish, and configuration prior to ballizing was first studied. Based on the available literature, a ball size was selected and a tool fabricated (Figure 1). A number of holes were reamed to 0.002 inch (50.8 μm) under the finished size. The tool was pushed through the holes, then the hole size and finish were inspected. Based on the results, the ball size was adjusted and the tests performed again (Table 1). The tests revealed the following.

- The amount of material is important: if no material is left, the ball cannot work the hole sufficiently to remove the machining marks. If the hole is too small, the ball will not pass through.

Figure 1. Four Microinch (101 nm) AA Ball Tool Used to Finish 0.312 Inch (7.938 mm) to 0.500 Inch (12.7 mm) Through Holes in Vanadium Modified Steel

Table 1. Hole Surface Finish Results

Hole Number	Surface Finishing Methods					
	Ball Finishing* With Hole Preconditioned by Carbide Reamer		Ball Finishing* With Hole Preconditioned by Boring		Jig Grinding With Carbide Rotary Burr (Holes Reamed Before Jig Grinding)	
	Hole Finish (AA)***		Hole Finish (AA)		Hole Finish (AA)	
	Before	After	Before	After	Before	After
1	110	22	38	12	120	12
2	94	20	35	12	160	12
3	80	18	40	14	96	10
4	74	14	31	10	100	8
5	80	14	38	14	85	10
6	100	18	25	8	70	12
7	96	16	34	14	92	12
8	114	18	40	14	100	6
9	90	18	28	11	140	8
10	110	20	38	22**	125	10
11	90	18	39	14	110	10
12	84	14	35	10	100	12
*Ball surface finish 6 AA **Hole had tear marks which were not removed by the carbide ball ***1 microinch = 25.4 nm						

- The speed of the ball through the hole must be constant to avoid adversely marking the hole.
- The hole preparation must be developed for each hole size and for the particular material under study.

During the above tests, it was quickly determined that the ball surface finish was very important to the finish of the ballized hole. The tool finish versus the hole surface finish had a break-even point for this project at a ball finish of 4 microinches (101 nm) AA. The additional time spent to improve a 4 AA ball finish did not significantly improve the finished hole.

The lubricant used had some bearing on the hole finish. STP oil additive resulted in the best finish while holding the other parameters as constant as possible. Because some of the holes were blind holes, the ballizing tool had to be redeveloped for these holes. The tool must have the capability to work the hole very close to the bottom and still maintain the size and finish requirements. Various tool configurations were evaluated and eliminated. The final configuration is shown in Figure 2.

Simultaneous with the above activity, it became apparent that the blind hole ballizing presented another problem. The tool's progress into the hole trapped air, and increased the air pressure, which was unexplainably detrimental to hole finish and produced a protrusion on the far side. To eliminate this problem, a hole was machined through the end of the tool and vented by way of an intersecting hole behind the working area of the tool.

The jig grinding method proved to be superior to the other methods from both a hole size and finish standpoint. This method is time-consuming, however, requiring up to 60 minutes a hole. The jig grinding stones needed frequent dressing to achieve the required finish and maintain hole tolerance. A carbide grinding tool (rotary burr) achieved good results: surface finish suffered only slightly, hole size was maintained, and a reduction in time of 30 minutes a hole resulted.

Table 2 lists the methods studied and denotes the expected obtainable values of surface finish and hole size.

ACCOMPLISHMENTS

Either ballizing or jig grinding will satisfy the design requirements. It should be noted, though, that the work was done on 4330 vanadium modified steel and will not necessarily produce the same results with other materials.

Figure 2. Four Microinch (101 nm) AA Tool Used to Finish Blind Holes Within 0.010 Inch (0.25 mm) of the Bottom 0.020 Inch (0.5 mm) of the Far Surface

Table 2. Comparison of Alternatives

Method	Tool Used	Metal Removed		Surface Finish Obtained (Microinches)**	Ball Size (Inch)	Machine
		Size Before (Inch)*	Size After (Inch)			
Ream	Carbide Reamer	0.005 Diameter Undersize	To Size	80 AA to 100 AA		Sip, De Vlieg
Bore	"Microbore" Carbide boring tool	0.002 Diameter Undersize	To Size	30 AA to 60 AA		Sip, De Vlieg
Lap	Nema Lap Aluminum oxide and cut maximum oil slurry	0.0005 Diameter Undersize	To Size	10 AA to 16 AA		Sip
Ballize	See sketch Solid Carbide	0.3746 Diameter 0.3120 Diameter 0.4997 Diameter	0.3750 Diameter 0.3126 Diameter 0.5002 Diameter	8 AA to 14 AA	0.3768 Diameter 0.3138 Diameter 0.5020 Diameter	De Vlieg Horizontal Mill
Jig Grind	Carbide Burr	0.002 to 0.004 Diameter Undersize	To Size	10 AA to 12 AA		Moore Jig Grinder D/163
	Stone	0.002 to 0.004 Diameter Undersize	To Size	6 AA to 10 AA		Moore Jig Grinder D/163
*1 Inch = 25.4 mm **1 Microinch = 25.4 nm						

Jig grinding proved to be much faster than anticipated, but was still more time-consuming than ballizing. Jig grinding is more suited to short run, non-production work; the ballizing, though requiring much more development, will result in a much more efficient process.

FUTURE WORK

Although two methods were developed to successfully produce the desired hole size and finish, inspection methods must be improved to standardize inspection results. Different values were often obtained for the same hole, and these variations often exceeded the hole tolerance. It is suggested that this problem be studied and eliminated because these kinds of hole size tolerances are becoming more commonplace.