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Twist drilling of Haynes 282 superalloy

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Abstract

Experimental work is presented detailing tool wear and workpiece integrity results when drilling next generation Haynes 282 aeroengine casing material using coated carbide tooling with high pressure (50 bar) cutting fluid. Testing involved variation in cutting speed and feed rate typically used for Ni-based superalloys. At lower combinations of operating parameters, flank wear was generally uniform however extensive wear/fracture of the tool corner chamfer was evident in the majority of tests. Adhered material up to ~250 μm long was observed on all machined surfaces, which increased with worn tooling and at higher operating conditions. Microhardness results showed an increase in hardness (up to 50 $HK_{0.05}$ above the bulk) within the first 50 μm. Surface/subsurface microstructural damage consisted of deformed grain boundaries up to a depth of ~15 μm with a discontinuous white layer of up to ~6 μm from the surface.

Keywords: Drilling, Nickel alloy, Surface integrity

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1. Introduction

Haynes 282 is a wrought, gamma-prime strengthened nickel-based superalloy developed primarily for high temperature structural applications including the casings used in gas turbine aeroengines, see Fig 1(a) [1]. Principal benefits include a unique combination of creep strength (stress of 221 MPa to produce 1% creep in 100h at 816ºC), thermal stability (UTS of 975 MPa after exposure at 871°C for 1,000 hours) and weldability, which is superior to other equivalent commercial alloys such as Waspaloy [2]. Due in part to its relative newness, there is currently very little information in the literature regarding preferred

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machining conditions for this alloy and associated effects on workpiece surface integrity. The paper details experimental results following twist drilling which is a key process for the production of features such as bosses on casings.

2. Experimental work

All tests were performed on a Matsuura FX5 CNC machining centre with a maximum spindle speed of 20,000 rpm rated at 15kW. The Haynes 282 workpiece material (Ni-20Cr-10Co-8.5Mo-2.1Ti-1.5Al-1.5Fe-0.3Mn-0.15Si-0.06C-0.005B) was precipitation heat treated to give a bulk hardness of ~32HRc and was supplied in the form of plates measuring ~100 x 100 x 6.5 mm. Typical grain size ranged from ~50 to 250 µm and the microstructure was interspersed with carbide particles of up to ~12 µm in length; see Fig 1(b). Workpiece samples were held in a bespoke fixture fabricated with an array of 10mm diameter clearance holes to allow through drilling of the workpiece plates. Cutting fluid (water based emulsion) was channeled via a through tool adapter mounted onto the main spindle at a pressure of 50 bar and flow rate of ~6 l/min. The tools employed were twin lipped helical fluted 8mm diameter, TiAlN coated carbide drills (product code: SD203A-8.00-27-8R1-M). Tool wear was measured using a Wild microscope and a toolmakers table with digital micrometer heads giving a resolution of 0.001 mm.

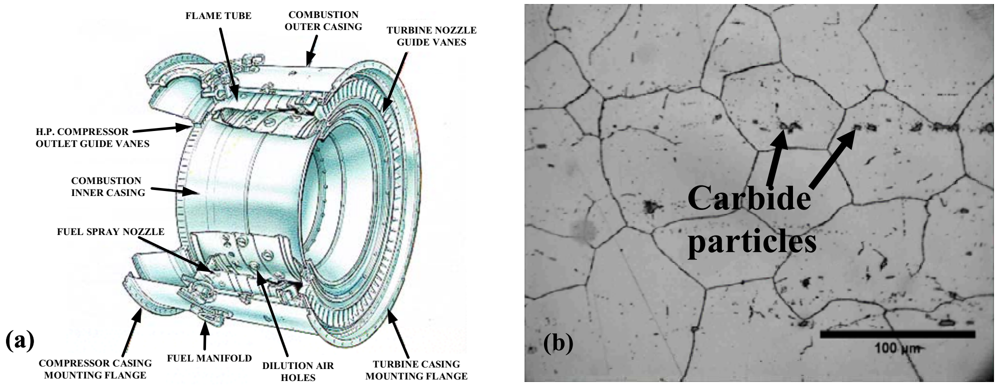

Fig. 1. (a) Schematic of aeroengine combustion casing [1]; (b) typical microstructure of Haynes 282

Surface roughness along the length of selected holes was measured using a Taylor Hobson Form Talysurf 120L with a cut off length of 0.8 mm and evaluation length of 4.0 mm. For workpiece surface integrity evaluation, selected samples were sectioned by electrical discharge wire machining (EDWM) before hot mounting in bakelite and grinding/polishing using SiC paper and diamond suspension. Etching used Kallings No. 2 reagent. A minimum of 500 µm of material was removed to ensure that sections were free of any damage due to the EDWM process. The top view of the hole was ground and polished to reveal a section 1mm from the workpiece surface while the axial view was similarly prepared to reveal the centre section of the hole. Microhardness depth profile measurements were taken using a Mitutoyo 810 hardness testing machine with a Knoop indenter and 50 g load. Three profiles on each section were taken at 10µm intervals from the surface until bulk hardness was achieved, with the average for each depth calculated. Selected workpiece surfaces and cross-sections were analysed using a Leica optical microscope running Buehler Optimet software, together with a JEOL 6060 scanning electron microscope (SEM). Experimental variables were cutting speed and feed rate with Tests 1 to 4 carried out utilising two different cutting speeds (low and medium) and two feed rates (low and high) recommended for superalloys. Tests 5 to 7 were executed at elevated cutting speeds (high & very high), in order to achieve higher material removal rates. Unfortunately commercial concerns restrict the publication of the exact operating parameters. The tool life criteria was a maximum flank wear of 500 µm on any individual cutting edge or uniform flank wear up to 250 µm averaged over both edges. An additional criterion was a maximum of 130 holes drilled (845 mm drill depth) per tool.

3. Results and discussion

The results of tool life trials for all tests are detailed in Fig 2(a). Tests 1, 3 and 4 showed steep initial wear rates (up to ~75 µm within the first 65 mm depth drilled), followed by a more gradual progression for the remainder of the experiment. Average drill flank wear (VB) in the three tests did not exceed 125 µm even after a depth drilled of 845mm. At this point, Test 1 with the lowest combination of cutting speed and feed rate showed the lowest flank wear (< 100 µm). A ~10 µm rise in tool wear was observed following an increase in cutting speed to the medium level (Test 3) while raising the feed rate (Test 4) resulted in a further increase in drill wear of ~22 µm. Extensive wear/fracture of the tool corner chamfer such as that illustrated in Figure 2(b) was evident in all the other tests. Catastrophic chipping at this location has also been reported by Sharman et al. [3] and Chen and Liao [4] when drilling Inconel 718. The performance of Haynes 282 was worse than that of RR1000 using Test 1 parameters. Tool life (VB_{max}) for the latter was reported as being ~90 µm after a depth drilled of 1800 mm [4].

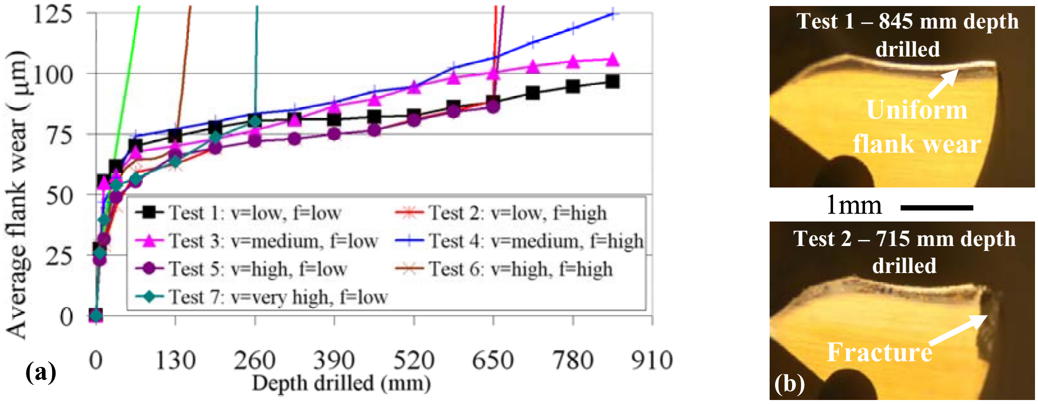

Fig. 2. Tool life results; (a) flank wear against depth drilled; (b) wear scar photographs

The majority of surface roughness readings were found to be within the range of 0.4 to 0.6 µm Ra with only Test 6 resulting in abnormally high values during the early stages of tool wear. In general, Fig 3 shows that as depth drilled (and flank wear) increased there was a reduction in the surface roughness by up to 33%. No trend was indentified linking workpiece surface roughness to the operating parameters employed. This was possibly due to the irregular nature of the smeared/adhered workpiece material typically seen on the machined surface. Similar Ra values of 0.5-1.5 µm were recorded when drilling Inconel 718, with the majority of tests showing a reduction in surface roughness as tool wear increased [3]. In general, the level of burring encountered was not excessive, with micrographs showing a maximum of ~250 µm in the radial direction. Tests at higher operating parameters showed greater levels of burring and an increase in flank wear also appeared to cause a marginal increase. No significant fracture/breakout was observed on any hole. SEM images taken of the entry location appear to show smearing of burrs over the edge of the hole whereas cracks within the burrs were visible at the hole exit, see Fig 4. Similar entry and exit burring was reported by Dornfeld et al. [6] when drilling Ti-6Al-4V, with burr dimensions ranging between 100-200 μm depending on the operating conditions used.

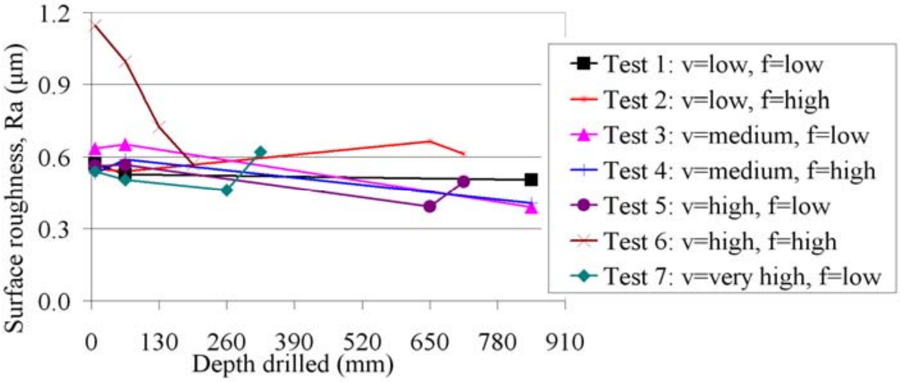

Fig. 3. Workpiece surface roughness against depth drilled

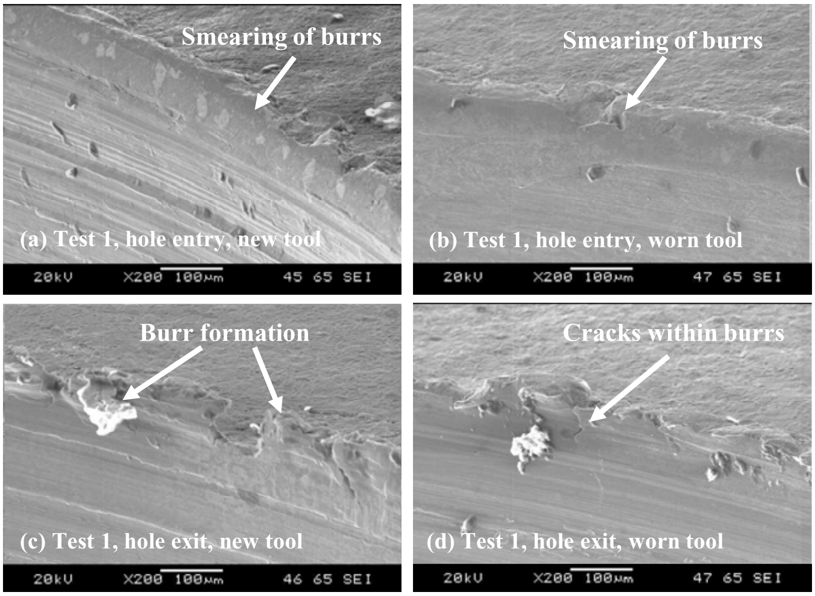

Fig. 4. Images of burring; (a) Test 1 (6.5 mm depth drilled), entry; (b) Test 1, (845 mm depth drilled), entry; (c) Test 1, (6.5 mm depth drilled) exit; (d) Test 1, (845 mm drilled) exit

Fig 5 shows examples of smearing/adhered material observed in Test 1 with a new tool (6.5 mm depth drilled) and in Test 7 just prior to drill failure (260 mm depth drilled). In general, higher operating parameters (more severe conditions) caused an increase in the level of re-deposited material, as did worn tooling. Similar levels of surface smearing when drilling Inconel 718 due to trapped swarf between the flute margins and hole wall have been reported [3]. However, such randomly distributed surface smearing causes concern as it may obscure any additional workpiece surface damage.

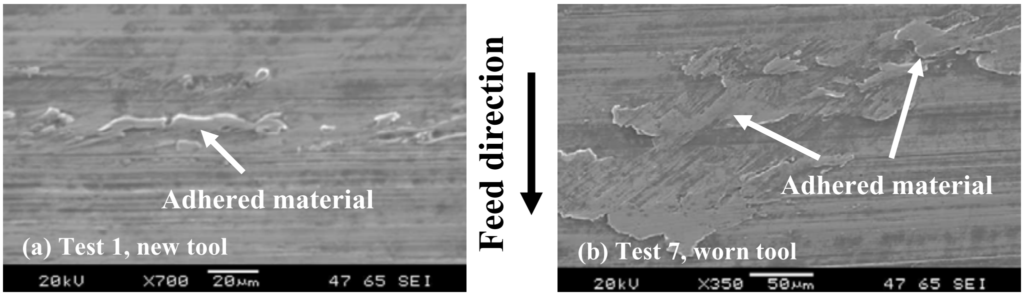

Fig. 5: Drilled surface; (a) Test 1, hole 1; (b) Test 7, hole 40

In terms of microhardness evaluation, most tests showed a similar depth profile with an initial strain hardened layer of up to 120 $HK_{0.05}$ above the bulk hardness of ~480 $HK_{0.05}$ to a depth of ~50 µm from the machined workpiece surface. There appeared to be a correlation between hardness and average flank wear levels, with higher tool wear inducing harder machined surfaces, see Fig 6. In general, measurements taken in the radial direction were only marginally lower than the measurements obtained in the axial direction. The degree of strain hardening was also more pronounced at higher cutting speeds and feed rates. The magnitude of the hardened layer (above the bulk value) in Test 1 ranged up to 40 $HK_{0.05}$, which increased to approximately 90 $HK_{0.05}$ in Tests 6 and 7 and was associated with the more intense heating-cooling cycles at the higher operating parameters [7].

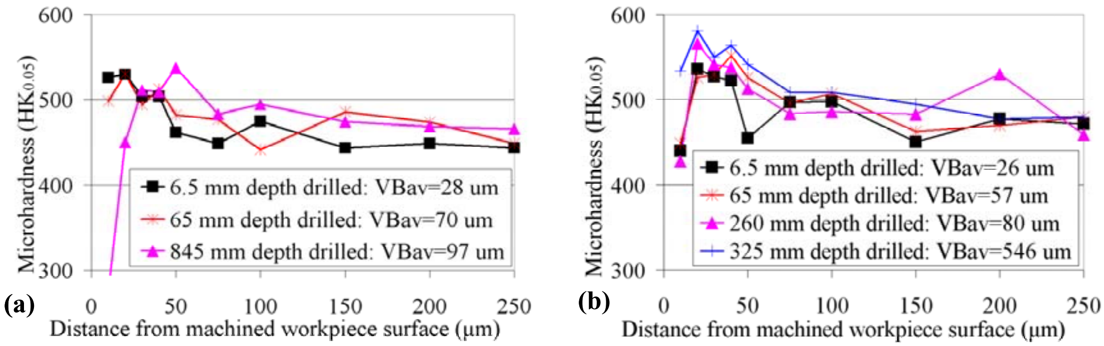

Fig. 6. Microhardness depth profiles in a radial direction; (a) Test 1; (b) Test 7

Surface/subsurface microstructural damage seen in all holes consisted of deformed grain boundaries up to a depth of ~15 µm and a discontinuous white layer of up to ~6 µm thick. Fig 7 shows examples from Test 1 (after 6.5 mm depth drilled) and 4 (after 845 mm depth drilled). Cutting speed appeared to be the dominant factor with the depth of white layer increasing from ~2 µm at low cutting speed to ~6 µm at high and very high cutting speeds due to the higher machining temperatures. The results were comparable to the work of Soo et al. [5] and Kwong et al. [7] when drilling powder HIPped and coarse grain RR1000 superalloy respectively. Smeared/adhered material up to 20 µm deep was also found on the workpiece surface which is in accordance with the SEM images of the drilled holes, see Fig 5. Elevated operating parameters and more severe cutting tool flank wear led to greater levels of smearing as well as grain deformation. Popa et al. [8] reported that flank wear had the greatest effect on the depth of the affected/damaged layer when drilling nickel alloys. For aerospace applications, it is likely that a post processing operation such as reaming or mill boring would be required to remove the white layer and re-deposited material.

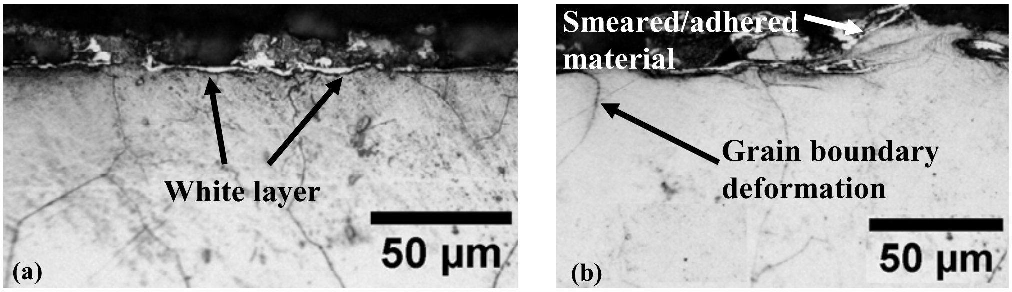

Fig. 7. Surface/subsurface cross-sectional micrographs; (a) Test 1, hole 1; (b) Test 4, hole 130 (VBav =125 µm)

4. Conclusions

- Tool flank wear at lower operating parameters was generally uniform however extensive wear/fracture of the tool corner chamfer was evident on more than half the tests.
- Increasing flank wear from 30-100 µm caused on average a reduction in surface roughness Ra by 33%. Changes in operating parameters appeared to have limited effect on surface roughness.
- Burrs were up to 250 µm in height generated on both hole entry and exit in the majority of specimens analysed. The only visible defect on the workpiece surface was adhered material up to ~250 µm in length and width. Highest levels of smearing were seen with worn tools at high operating parameters.
- Surface/subsurface microstructural damage was generally confined to bent/deformed grain boundaries up to a depth of ~15 µm and discontinuous white layers up to ~6 µm thick from the workpiece surface. These observations were comparable with results obtained when drilling Inconel 718 and RR1000.

Acknowledgements

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