



Porosity Reduction in a High Pressure Die Casting Through The Use of Squeeze Pins

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Introduction

The high pressure die casting process enables the casting of complex thin walled castings with good surface finish and dimensional tolerance. Molten metal is generally injected into the cavity via thin gates at high velocities promoting turbulent flow that can result in air entrapment. Internal porosity is of significant concern for die casters, especially when castings receive subsequent machining operations. Whether porosity in a component results in the part being scrapped depends on its location, size and distribution. A small number of large pores may be unacceptable, while a component of the same density that has smaller more dispersed porosity may be acceptable.

Over a six-month period, Ford Australia's high pressure aluminium casting operation grew from producing three components to six components at a significantly higher production rate. Such an increase in output placed particular focus on capacity limiting issues within the area. As a result, this work focuses on a large die (figure 1) used to produce four front and four rear cam caps. The front cam cap is a thin rib-like component that contains a thick "head" region that solidifies last, and it is into this hotspot that three oil galleries are machined. Leakage between the galleries is undesirable and the part's acceptance standard specifies defects visible on machined surfaces to be neither within 3mm of each other nor greater than 1mm in diameter.

Many authors [1-4] characterize the appearance of shrinkage porosity as angular in nature with a rough dull surface and evidence of dendritic structure, while gas porosity tends to be more spherical with a smooth shiny surface. However, shrinkage and gas porosity do not always form independently, and pores can quite often be attributed to a combination of both mechanisms. The reduction of porosity resulting from entrapped gases in high pressure die casting has been the focus of much research [5-11], with the need for accurate shot control and acceleration profiles derived from shot sleeve fill percentages being well established. However, these variables only control the amount of gas present in a casting. A die design that does not adequately compensate for solidification shrinkage may receive little benefit from improved shot control.

Small diameter holes in die castings are most commonly formed using core pins. When the holes are located in particularly thick regions of the castings however, solidification shrinkage in the surrounding region may be inadequately fed, leading to porosity that becomes exposed during subsequent machining operations. Should core pins be appropriately

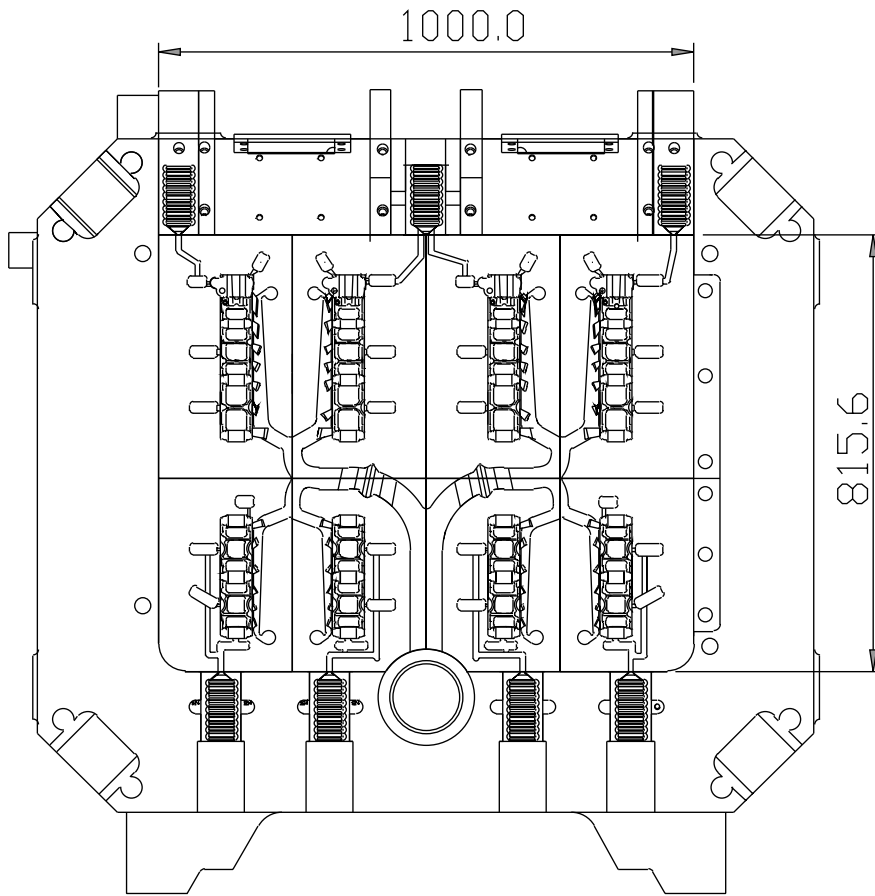


Figure 1: Moving half of the cam cap die (dimensions in mm).

positioned, their replacement with squeeze pins represents an opportunity to compensate for solidification shrinkage without significant geometry changes to a component. A greater understanding of the situations in which squeeze pins are effective in reducing porosity may allow them to be used with confidence at the original die design stage. This may facilitate the effective casting of traditionally difficult components with large variations in section thickness.

Casting with the Sliding Core Configuration

The original die design used a sliding core mechanism with stationary pins to create a phaser hole in the head region of the front bearing cap during casting. Initial casting of the cam caps was problematic

with intermittent blow-outs around the sliding core combined with consistently high scrap rates due to porosity in the critical head region. Internal porosity generally forms from entrapped gas, solidification shrinkage, or a combination of both and the corrective actions can be vastly different depending on which mechanism is dominating. To identify the source of the defects prevalent in the cam cap, computer modelling, visual and microscopic examination techniques were employed.

MAGMAsoft simulation software was used to evaluate the solidification conditions in the casting. The solidification time produced by software is defined as the time taken for the selected alloy to cool to the equilibrium solidus temperature – in this case 479°C - following

complete filling of the die cavity. Figure 2 visually presents the solidification times for two front cam caps.

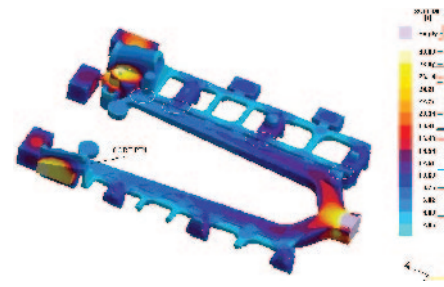


Figure 2: MAGMAsoft solidification simulation of two front cavities (circles indicate location of the gates on the top cavity while the location of the stationary core pin is identified on the lower cavity).

The casting in the foreground has been sectioned longitudinally to show the extent of the hot spot in the centre of the head region while the circled regions highlight the locations of four, 2mm thick gates that facilitate the filling of each front cam cap. Although there is a gate next to the hot spot, such narrow gates generally solidify before the bulk of the casting resulting in internal porosity despite the application of intensification pressure [12]. The solidification times presented in Figure 2 (approximately 23s for the hot spot and 4.5s for the adjacent gate) indicate that this is the case for the front cam caps.

The scrapped casting featured in figure 3 has been wire cut through the head region to reveal a large shrinkage void. The appearance of this defect with a dull angular surface is typical of defects found in castings produced with the sliding core and is primarily attributed to solidification shrinkage. Defects in this region create the possibility of leakage between oil galleries machined in the area and are not acceptable.

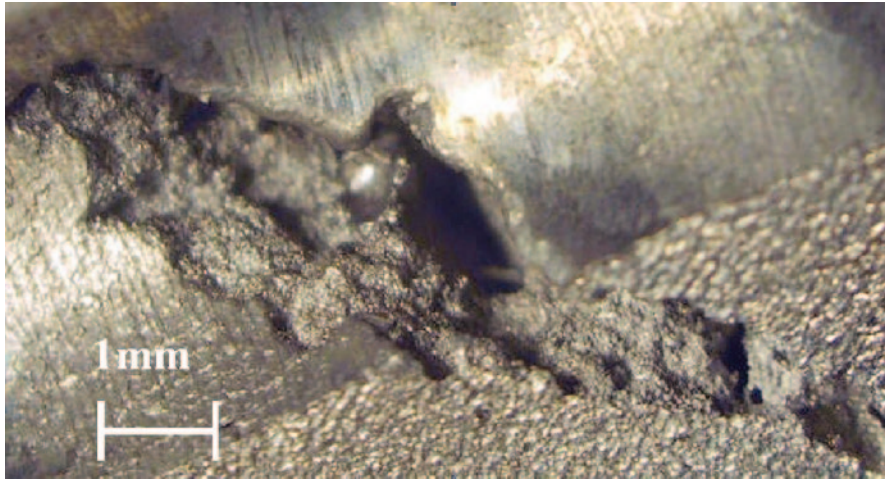


Figure 3: Shrinkage defect in a component cast with the sliding core.

In the case of micro-porosity, shrinkage voids are typically observed between primary dendrites where the eutectic would usually be expected. However this generalization does not apply as strictly to the formation of macro-porosity where a combination of contributing mechanisms is more likely. Figure 4 shows the edge of a void (right half of figure) suspected to have been formed by the shrinkage mechanism. The region at the pore edge has a much lower percentage of eutectic than the bulk of the casting. The small void in the bottom left of the micrograph is reasonably spherical with substantial eutectic

surrounding it, suggesting that there is also a contribution from gas porosity in the critical region of the casting.

Squeeze Pin Modification

It has been shown in a feasibility study by Kim [12], that squeeze pins can be used to compensate for shrinkage defects in industrial aluminium casting. Given that the cam caps had a large, poorly fed hotspot, and the major mechanism contributing to porosity formation in the critical region of this component was most likely solidification

shrinkage, replacement of the stationary core pins with squeeze pins was recommended and a squeeze pin modification was designed by the tooling supplier.

The volume of the critical head region in the casting without the stationary core pin is 104.67 cm³ while the volume of the squeeze pin used in the cavity is 2.83 cm³. The pin volume represents 2.7 percent of the head region in which it operates, and the displaced un-solidified metal feeds the solidification shrinkage that is not eliminated by intensification pressure from the plunger. Squeeze pins for each of the four cavities are engaged at the same instant, controlled by a timer started when the piston reaches high shot changeover position. The squeeze pin modification was designed in a reversible “bolt-on, bolt-off” configuration that allowed switching between the sliding cores and squeeze pins within 8 hours. Such a design allowed a production window to be made for a squeeze pin trial, during which if significant problems had been encountered with the application of the squeeze pins, the die could have been changed back to sliding core formation without affecting supply of cam caps to the customer.

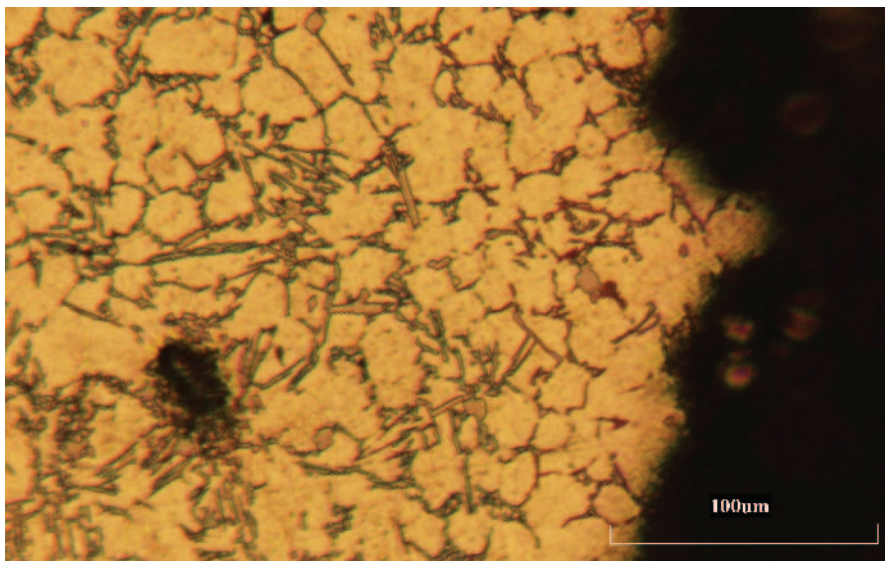


Figure 4: Microstructure at the edge of a shrinkage defect.

Squeeze Pin Timing Trials

Experimental Procedure

Trials were conducted to determine the optimum timing for engagement of the squeeze pins to reduce porosity formation in the critical region of the cam cap. This component is cast with a 2000 ton cold chamber high pressure die casting machine, which operates with the parameters summarized in table 1

when casting cam caps. The alloy used in the casting plant is supplied to the Australian standard CA 313 with the composition presented in table 2.

Parameter	Setting
Low shot speed	0.4 m/s
High shot speed	2.4 m/s
Shot sleeve fill percentage	50%
Melt temperature	680°C
Cycle time	80s
Squeeze pin pressure	3000 bars

Table 1: Cam cap casting parameters.

therefore a maximum pin timing of 3.5s was specified. The timing was trialed at 0.5s intervals from zero to 3.5 seconds with 7 shots for each setting. The die produces four front cam caps per shot, which corresponds to a sample size of 28 front cam caps per timing interval. Three of four castings from each shot proceeded through the machine line while one cavity was destructively tested. To obtain density measurements for the critical head region, trial cam caps selected for destructive examination were sectioned behind the critical solid head region. This section was weighed in air, and then weighed while suspended

Element	Al	Si	Cu	Fe	Zn	Mn	Mg	Other Total
%	Bal	9.0-10.0	2.5-3.5	0.7-1.0	< 1.0	< 0.5	< 0.3	< 0.5

Table 2: CA 313 alloy composition.

Rating	Description
1	0 porosity visible on any surface
2	1 defect << 1mm
3	2-4 defects << 1mm
4	1 defect between 0.5 and 1mm
5	2 defects, 1 approaching 1mm
6	More than 2 defects, up to 1mm but within 3mm of each other
7	Pore > 1mm in any area
8	Defects smaller than 1mm but within 3mm of each other
9	Between 2 and 4 defects > 1mm
10	Gross porosity

Table 3: Experimental inspection standard.

Preliminary experiments had determined that for pin engagement timings greater than 4s, pins did not reach their full stroke. This result was unacceptable to the customer;

in distilled water thrice to ensure reproducibility. Using a theoretical density of 2.77 g/cm³ for the alloy CA 313, the percentage porosity was then calculated.

For cam caps proceeding through machine line, an experimental inspection standard was generated ranging from 1 to 10 (table 3). Three small oil galleries are machined through the thick section of the front cam cap connecting to the large through bore. The surfaces of the oil galleries and through bore were inspected, with the number and size of the defects in all areas dictating the qualitative rating assigned to that casting. The acceptance standard that front cam caps were required to pass specifies that defects on machined surfaces must not be within 3mm of each other, and must be not be greater than 1mm in diameter.

Results & Discussion

Figure 5 presents the results from visual inspection of cam caps for each pin timing interval. The average porosity rating decreased from 10 (gross porosity) for engagement times of 0 and 0.5s to between 2 and 4 (within the acceptable range) for longer engagement times. For engagement times of 0 and 0.5s, 100 percent of castings were rejected post machining. This was reduced to 5 percent for a pin timing of 1s and 0 percent for 1.5s.

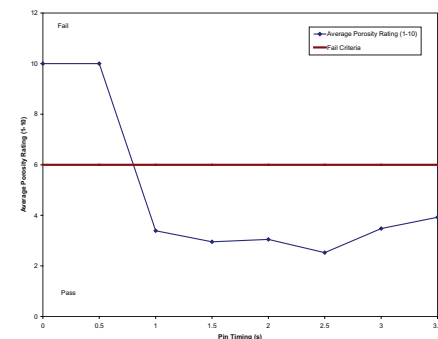


Figure 5: Visual inspection of trial castings post machining.

The porosity measurements presented in Figure 6 correspond very well with the average poros-

ity ratings in figure 5. Both show a steep drop in porosity when pin timing is increased from 0.5s to 1s with the level remaining reasonably static until 3s, after which a notable increase is observed. At pin activation times greater than 3.5s not all of the four squeeze pins complete their full stroke of 25mm, since solidification is so far progressed that the component has enough strength to resist the pin force of 3000bars. In this event, the area over which beneficial feeding effects from the squeeze pin are realized is decreased, resulting in porosity at the extremities of the critical region far from the pin.

When compared to components cast with the die in sliding core formation, casting using the squeeze pin engagement at 1.5s resulted in an 80 percent decrease in the volume of porosity in the critical region of this casting. At pin engagement times of less than 1s, the weights of the whole castings are substantially lower than those for times of 1s or above (figure 6). At these early engagement times it seems that the squeeze pins

may push a significant amount of liquid metal to other parts of the cavity. Should metal be displaced to regions such as overflows, chill vents or the runner, the weight of the trimmed part will consequently be lower as seen for engagement timings of 0 and 0.5s. If the pin reaches full stroke before significant solidification has occurred, pressure will be dispersed through the casting and there will be no additional pressure forthcoming to feed shrinkage. The time from when the piston tip reaches high shot changeover position until filling of the cavity was measured as 80ms by the cast-pulse shot monitoring system. This is significantly less than the time required for the squeeze pins to reach full stroke, so for the purposes of this work, it is assumed that at squeeze pin engagement times of 0s, the cavity is full before significant movement of the squeeze pin has occurred.

Results published by Kim [12] showed there is an interaction between squeeze pressure and engagement timing. Higher pressures facilitated later engagement times,

but optimum results were achieved using a compromise of both factors. Even though the highest squeeze pressure of 3000kg/cm² used by Kim is very close to that used in this work, the window for pin timing to achieve full stroke and maximum densification was at best 1s. Kim [12] presented no solidification simulation for the casting featured, however part geometry suggests that the hot spot may not have been as large or concentrated as is the case with the cam cap for which the squeeze timing window is 2s.

In either sliding core or squeeze pin configuration, hot spots in the critical region of the cam caps (Figure 7) are simulated to have a solidification time five times that of the gate that feeds them. In the sliding core configuration (top) shrinkage defects were consistently produced as there is a significant amount of solidification that occurs with limited feeding. The hot spot generated in the die subsequent to the squeeze pin modification (bottom) is much larger without engagement of the squeeze pins, however feeding is facilitated by the engagement of the squeeze pin at an appropriate time. This simulation characterizes the size of the localized hot spot that has been effectively naturalized with the use of a squeeze pin.

Sugijama [13] presented evidence that intensification pressure from the piston tip is only transferred to the cavity for 20 percent of the solidification time at the gate when the gates are 2mm thick. Should no pressure be transferred into the cavity due to plunger pressure after this time, it follows that pressure from a squeeze pin would be localized inside the cavity. Simulation of the cam cap predicted that the gate feeding the head region reaches the

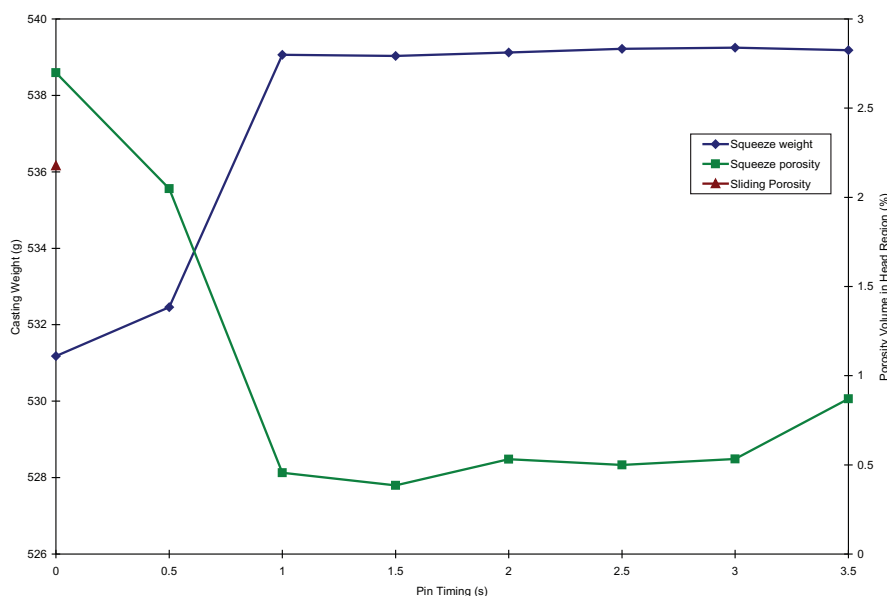


Figure 6: As cast weights and porosity measurements of the critical region for trial castings destructively tested.

solidus temperature of 479 °C between 4 and 4.5 seconds after filling of the cavity. Taking 20 percent of this solidification time gives a critical squeeze timing of 0.8 to 0.9s for the cam cap, which agrees well with the experimental data that shows the critical timing to be between 0.5 and 1s (Figure 5 and 6). The overflows in Figure 7 are of different orientation because the simulation was performed with cavity 1 in squeeze pin configuration and cavity 2 with the sliding core.

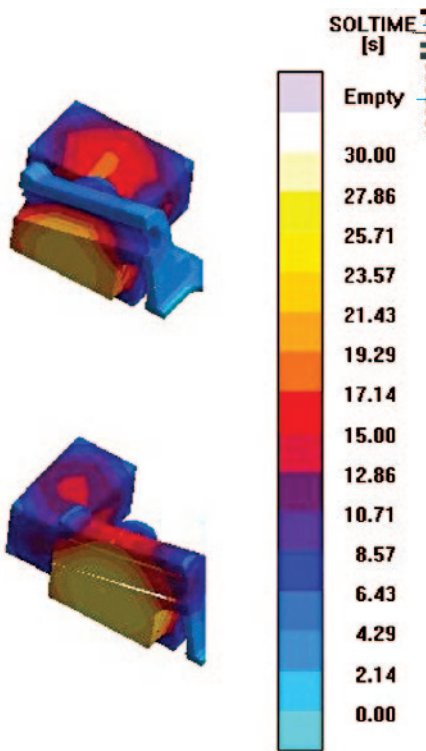


Figure 7: Solidification times for the critical region of the front cam cap in sliding core (top) and squeeze pin (bottom) configuration (assuming no engagement of the squeeze pin).

Conclusions

Squeeze pins have been implemented in an industrial environment to significantly reduce scrap rates in a high pressure aluminium die casting operation. For a large multi-cavity die with a local hot spot the implementation of squeeze pins resulted in an 80 percent volume decrease in porosity for the critical region.

This work has shown that squeeze pins can be effectively used to counteract shrinkage defect formation in poorly fed hot spots of high pressure die castings. This is achieved by reducing the volume of the die cavity subsequent to it being filled and a degree of solidification taking place at the gates. When casting with squeeze pins, there is a timing window for pin engagement that allows optimum porosity reduction. Part quality is relatively constant within this timing window, outside which the following will occur.

- If squeeze pins are engaged too early, the pressure disperses through the cavity before solidification proceeds to the point that shrinkage requires feeding, thus reducing the ability for a squeeze pin to counteract solidification shrinkage in a local area.
- If squeeze pins are engaged too late, solidification is allowed to progress to the extent that pin stroke will be limited, resulting in less effective porosity reduction.

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While studying towards an honors degree in Materials Engineering at the University of Queensland, Matthew worked as a member of the CAST (CRC for Cast Metals Manufacturing) research team investigating grain refinement. A final year thesis followed on the effect of grain refinement in secondary Aluminium - Silicon alloys, resulting in a paper that was presented at TMS 2003. Matthew is now affiliated with the Casting Centre of Excellence for Iron (Fe) and Aluminium Solidification (FAST), working towards his masters degree at Ford's aluminium casting plant in Geelong, Australia.

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After graduating in 1998 with a PhD in Engineering from the University of Queensland in the area of high pressure die casting of magnesium alloys, Matt has worked in the area of automotive and telecommunications component manufacture on a range of product development projects. For most of this time Matt was working as an R&D engineer in the automotive component manufacturing industry. In late 2001 Matt began working with the Cooperative Research Centre for Cast Metals Manufacturing (CAST). During his time with CAST he has been responsible for project managing a large industrially funded research project focusing on the design and process development of telecommunications components with particular emphasis on the production of these components using high pressure die casting rather than alternative manufacturing routes such as CNC machining. He has also been part of a CAST research team developing alloy and sand casting technology for the production of a magnesium engine block.

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Mark Nave obtained his Ph.D. from the University of Queensland in 2001 for research on solidification mechanisms in hypoeutectic Mg-Al alloys. Now based at Deakin University, his research covers a broad range of processes and materials, from deformation and recrystallization of steels and magnesium alloys to high-pressure die-casting of aluminium alloys. The results of his research have been published in international journals and conference proceedings and he has presented seminars on his work at universities and industrial research institutes around the world (Asia, Australia, Europe and North America). Awards Mark has received for his research include a symposium fellowship from the Australian Academy of Technological Sciences and Engineering.

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