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Copper Based Bi-metallic Core Pin Using DMD: Industrial Evaluation

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***Abstract*— Bi-metallic core pins were prepared and the performance was evaluated in a specially designed die that had the provision to investigate core pins under semi-industrial HPDC conditions. A comparison between bi-metallic core pin with that of tool steel revealed that bi-metallic core pin performed better in terms of soldering under HPDC environment. Due to slow cooling, die holding time needed to be increased in tool steel core pin to allow sufficient solidification of the casting part. The bi-metallic core pins also operated without any catastrophic failure in the clad which particularly substantiated the applicability of DMD deposited tool steel clad on copper alloy substrate to manufacture bi-metallic tooling.**

***Keywords*— HPDC; material build-up; DMD; core pin; soldering.**

I. Introduction

From the thermal fatigue test it was evident that tool steel clad on copper alloy substrate provided a level of strength against cyclic heating and cooling condition [1]. It proved resistance to the mismatch of co-efficient of thermal expansion between copper alloy substrate and tool steel clad and promoted the bi-metallic structure as a promising candidate for HPDC. However, induction heating thermal fatigue test does not subject the clads to the severe conditions that exist during HPDC, such as high velocity cavity filling, high pressure, solidification, casting ejection, die cooling, and lubrication. Therefore, it is necessary to evaluate DMD clads under conditions, which more clearly resembles those occurring in HPDC trials.

In this research accelerated die casting trials were performed by using a specially designed die, fabricated from H13 tool steel that had the provision to investigate core pins under same conditions [2]-[5]. The objective of this trial was to evaluate the performance of the bi-metallic core pin in the specially designed die under semi-industrial HPDC conditions.

II. Experimental Details

In the experiment, a 250 tons Toshiba cold chamber high pressure die casting machine was used. An accelerated high pressure die casting condition was applied during the casting trials that included extreme operating conditions of injection speed (50-55 m/s), holding pressure (70-75 MPa) and die holding time (30s). Aluminum alloy CA 313 was used as casting material and the melt temperature was maintained at 680°C in the crucible.

Two sets of core pins in which the basic difference was in the length were prepared for HPDC trials. In each set, one core pin was made from tool steel and another one was made from copper alloy. Fig 1 shows the schematic drawing of the core pins. Tool steel core pins were used in the trials to allow reference to current industrial practice and to compare its performance with bi-metallic core pins. Each of the copper alloy core pin was coated with protective tool steel clads by using POM DMD 505. A 316L stainless steel (SS) buffer layer (0.5 mm thick) was also deposited in between copper alloy substrate and tool steel clad. Chemical compositions of the materials are listed in Tables I, II and III. Short core pins were prepared to avoid the direct impingement of the injection of molten aluminium. The long core pins were specially designed so that it could be positioned in front of gate entry in the die cavity. Positioning the core pins in front of the die cavity gate provided the performance evaluation under direct liquid aluminium impingement condition.

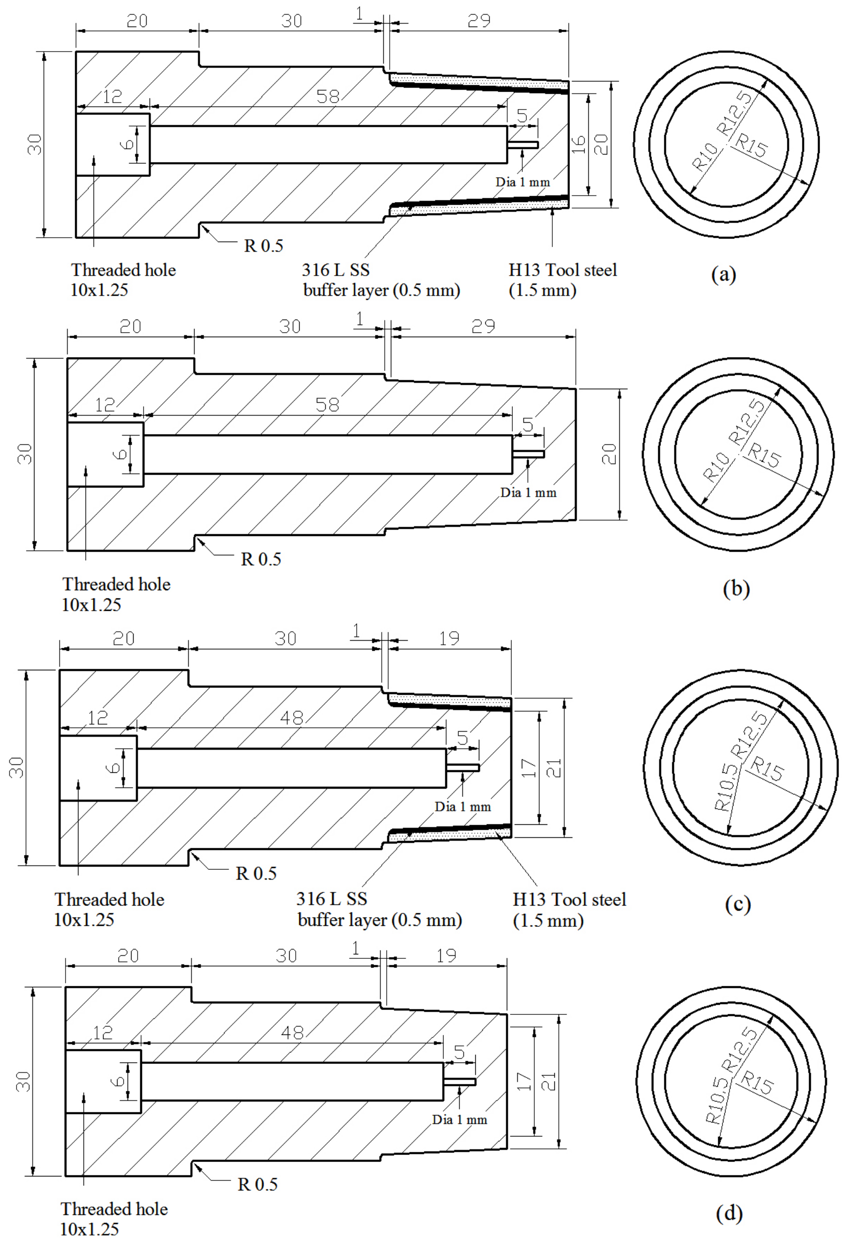

Fig 1: Schematic drawing of core pins prepared for the HPDC trials (a) long bi-metallic (b) long tool steel (c) short bi-metallic and (d) short tool steel core pin

TABLE I
CHEMICAL COMPOSITION OF COPPER ALLOY CORE MATERIAL

Element	Co + Ni	Be	Cu
Chemical composition	0. 5	1.9	Balance

TABLE II
CHEMICAL COMPOSITION OF H13 TOOL STEEL

Element	C	Mn	Si	V	Mo	Cr	Fe
Chemical composition	0.35%	0.4%	1%	1%	1.5%	5%	Balance

TABLE III
CHEMICAL COMPOSITION OF 316L STAINLESS STEEL

Element	Mn	Si	Mo	Ni	Cr	Fe
Chemical composition	1%	2%	2%	12%	18%	Balance

III. Results and Discussion

Gulizia et al. [3] reported that fifty HPDC cycles of the die used in this experiment was equivalent to several thousand cycles in an industrial HPDC machine. Therefore, each of the four core pins was designed for fifty HPDC shots. Fig 2 shows the core pins after finishing HPDC trials. During trials the short tool steel core pin however survived thirty five HPDC shots. Both visual observation and optical photograph of the casting hole that generated from the core pin revealed that the material build-up due to soldering initially started just after 10 shots. It was observed at the side of the core pin and eventually increased rapidly in next 20 shots. Fig 3 shows the material build-up trend on the short tool steel core pin surface. The material build-up at the surface was so rapid that at thirty fifth shot aluminium casting part stuck on the core pin surface and a piece of casting peeled off from the part and remained stuck with the core pin after forced ejection. This catastrophic failure particularly substantiated that the die holding time was not long enough for the casting part around the core pin to be solidified completely.

Fig. 2: Optical photograph of core pins after HPDC trials from left to right: bi-metallic short, bi-metallic long, tool steel long and tool steel short

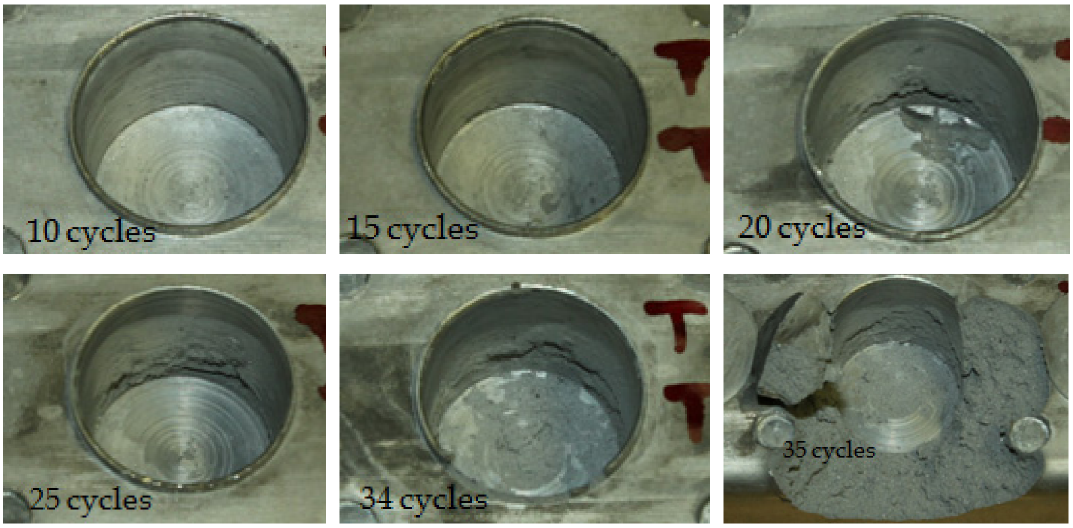

Fig. 3: Optical photograph of casting parts showing the material build up trend on tool steel short core pin due to soldering

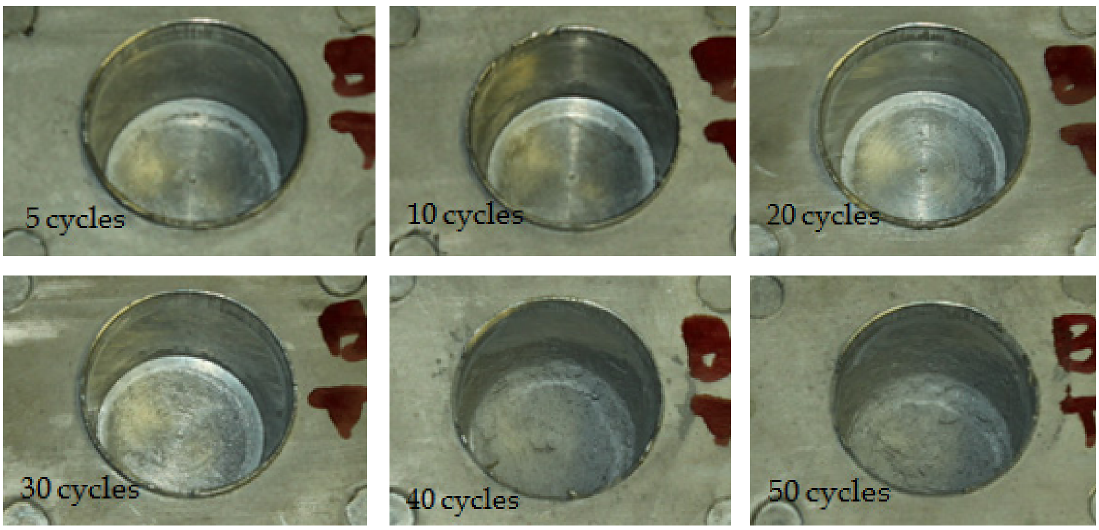

Fig. 4: Optical photograph of casting parts showing the material build up trend on bimetallic short core pin due to soldering

In contrast, short bi-metallic core pin survived designed number of HPDC shots without any catastrophic failure. Though it did not experience serious failure as in the case of short tool steel core pin, it appeared to have been coated with silvery aluminium layer. Fig 4 shows the material build-up trend of the short bi-metallic core pin. It was evident that unlike short tool steel core pin, soldering or material build-up initially started within five HPDC shots at the front face of the short bi-metallic core pin where copper was exposed to the molten aluminium. There was no sign of soldering on the side of the core pin before thirty shots. The material build-up however began on the side of the core pin after thirty HPDC shots and became thick gradually. It was also apparent from Fig 4 that front face of this core pin suffered from soldering more severely and exaggerated the material build-up at the side of the core pin.

Long bi-metallic core pin also survived designed number of HPDC cycles without experiencing any catastrophic failure. Fig 5 shows optical photograph of the material build-up trend of bi-metallic long core pin. Similar to bi-metallic short core pin, material build-up initially occurred at the front face within 10 shots. In addition, the direct impingement of molten aluminium caused significant soldering on the area tangent to the injection gate within 20 HPDC shots. Conversely, long tool steel specimen endured only 11 HPDC shots before the casting stuck on it due to severe soldering. Fig 6 shows optical photograph of the material build-up trend of tool steel long core pin. It experienced soldering so harshly within 12 shots that the holding time required to be increased by 30 seconds for proper ejection of the casting part. The extended holding time allowed sufficient solidification of the casting part around the core pin so as not to stack with it (Fig 6, 14th shot). But it lengthened the die holding time by 100% which in turn increased the cycle time to large extent. The inevitability of increase in die holding time for tool steel core pin particularly confirmed that bi-metallic core pin was able to transfer heat at a faster rate compared to tool steel core pin. The quick extraction of heat from the casting part around the core pin surface provided rapid solidification and unlike tool steel core pin, the part could not get stuck with the bi-metallic core pin.

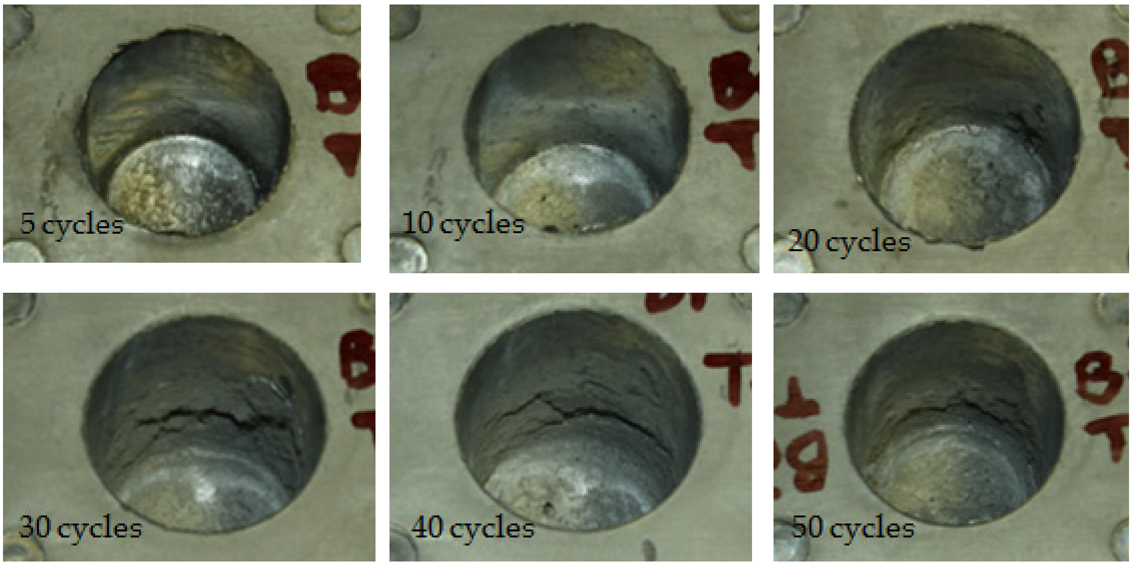

Fig. 5: Optical photograph of casting parts showing the material build up trend on bimetallic long core pin due to soldering

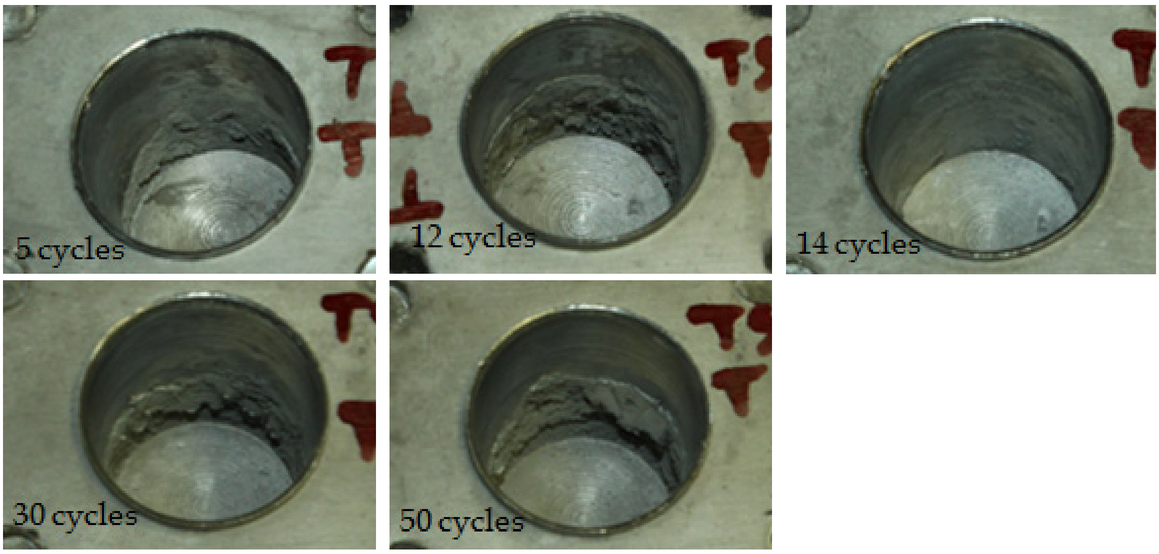

Fig. 6: Optical photograph of casting parts showing the material build up trend on tool steel long core pin due to soldering

IV. CONCLUSIONS

Though each of the four core pins was designed for fifty HPDC shots, tool steel core pins could not survive intended number of HPDC shots during trials and resulted catastrophic failure due to severe soldering. This catastrophic failure particularly substantiated that the die holding time was not long enough for the casting part around the core pin to be solidified completely. Unlike tool steel, bi-metallic core pins facilitated quick solidification of the casting material around the pin that in turn reduced the rate of soldering and survived the designed number of HPDC shots without any severe failure.

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