Applications of Multi-Material Systems: A Review

M. Velu*, S. Bhat
Department of Design and Automation, School of Mechanical Engineering, VIT University, Vellore, Tamil Nadu.
***Corresponding author: E-Mail: velu675@gmail.com; Phone: +91-9444551700**

ABSTRACT

This paper presents a few applications of multi-material systems. These systems provide scope for either reducing weight or cost of a product. The system employs either two or more metals within a component. Each of these will contribute to the functioning of the product as per their assigned role. The system consists of dissimilar metals. This imposes a great challenge to join them permanently without defects. This demands advanced welding techniques like Electron Beam welding (EBW), Laser Beam Welding (LBW), Diffusion Bonding (DB), Friction Welding (FW), Friction Stir Welding (FSW), Explosive Welding (EXW) and special filler metals. Mismatch in the material properties exists across the interface between the constituent metals. A few examples of multi-material systems include bimetallic worm gear; bimetallic gas turbine disc; multi-metal gear; bimetallic transition strips; dissimilar welded pipe and multi-layered bimetal laminate composites.

KEY WORDS: Multi-metal, Bimetallic, Mismatch, Worm gear, Turbine disc, Transition strip.

1. INTRODUCTION

In the current world scenario of depleting natural resources, optimal use of materials to reduce the weight, to enhance the life or to reduce the cost of a structure without compromising on its integrity and performance is assuming great importance. Hitherto, fibre reinforced plastics (FRP's) have been tried in this direction with great success but unfortunately their role has remained confined to small load and low temperature applications. Under high loads and in other possible stringent environments, metals and their alloys still offer the best choice. Of late, extension of monolithic metal systems to bimetallic ones has gained popularity. Layers of various metals possessing specific and distinct properties or layers of same metals with different microstructure/properties are bonded with each other in a non-homogeneous arrangement with discrete interfaces such that each metal layer performs a predefined role. Off late, advanced concepts of functionally graded systems possessing property gradient without distinguishable interfaces have also evolved from uncompromising requirements of multi properties in some critical structures. For instance, space vehicles requiring exterior skin plates with improved thermal properties for high aerodynamic heat resistance and the core with good mechanical properties like toughness. However, establishment of production techniques and test evaluation methods for functionally graded systems, like metal and ceramic based to name a few, that are suitable for such applications, are yet in the developmental phase.

Coming back to the bimetallic systems, they also were not feasible earlier since welding of dissimilar metals was impossible. But with the advent of solid state welding technologies like diffusion bonding, explosive welding, friction welding etc. that are capable of joining dissimilar metals at molecular levels with reasonably clean and strong bonds, bimetallic composites are fast turning into reality. Sustained efforts towards the use of special filler alloys for improving weldability between dissimilar metals by conventional gas and arc fusion welding has also yielded good results. Different combinations of metals and their alloys, viz. steel and copper, aluminum and copper, steel and aluminum, titanium and zirconium, steel and zirconium, titanium and lead etc. are reported to be welded with minimum defects by either of the above stated weld processes.

Bimetallic Worm Gear: Worm gears are normally made of bronze alloy, to reduce wear when it meshes with steel worm. Bronze is an expensive metal compared to steel and cast iron. Hence making worm gear fully with bronze is an expensive option. To bring down the cost without compromising on the functional requirement, a bi-metallic worm gear is made with bronze, only at the rim and the core with cast iron or steel. The bronze is spun cast over the steel hub to produce a worm gear blank as shown in Fig.1.

Figure.1. Bimetallic worm gear blank

Bimetallic gas turbine disc: In the current scenario of global warming, lowering emission level by way of improving efficiency in power generation gas turbine engines, assumes importance. This objective will be achieved by increasing the pressure ratios and turbine inlet temperatures, thus leading to more severe service conditions on high pressure rotor stage. Though ceramic thermal barrier coatings (TBCs) have been developed for the same purpose, they are not durable under high temperature cyclic conditions due to coating delamination problems (Zhu, 1999). As an alternate way, the concept of bimetallic gas turbine disc has been explored (Klotz, 2005). It permits different mechanical property requirements for the hub and the rim sections to be accommodated in a single disc structure without any coating, rather than compromising the fatigue and creep capability with a monoalloy disc. Hence delamination problems associated with TBCs can be avoided. Small scale bimetallic discs based on this concept for use in non-critical aeroengine systems are developed. The materials selected for manufacturing such discs are nickel based super alloy U720Li for hub section and nickel based super alloy IN738LC for rim section. The fatigue resistant U720Li bonded to a coarse grained, creep resistant IN738LC rim will potentially permit the turbine disc to be operated at elevated temperatures, hence improving overall engine efficiency. The said metals have been diffusion bonded in solid state, under hot isostatic pressure (HIP) followed by an isothermal forging if necessary. Microstructural investigations carried out on sections of as hipped and as hipped and forged discs shown defects/precipitates along the bond line. An irregular and poor quality bond line was observed in the as hipped and forged disc. Both of these results suggest that HIP diffusion bonding is not a suitable method for the manufacturing of dual alloy discs/components.

Multimetal gear: Figure.2, shows a gear made of many dissimilar steels. Advantages of Electron Beam Welding (EBW), such as minimum distortion, HAZ width, residual stresses and brittle zones in dissimilar metals joining (Sun, 1996) makes it a suitable joining process in the manufacture of such gears. Each of the steels present in this gear, contribute to the different functional requirements. Carburizing steel provides high hardness for teeth surface, constructional steel occupying a larger volume, brings down the material cost and quenched-tempered steel withstands the torsional load.

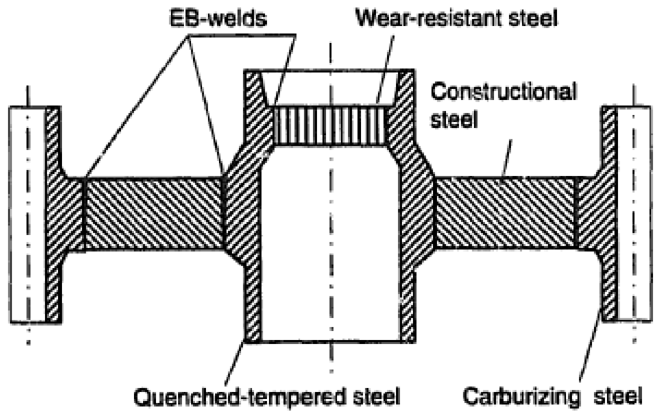

Figure.2. Multimetal gear

Bimetallic Transition Materials: Available in sheet, plate and tubular forms in combination of Al to steel and copper. They are made by rolling, explosion welding, friction welding, flash welding or hot pressure welding. They can be used for fusion welding aluminum to other metals.

Dissimilar welded pipe joint in fast breeder reactors (FBRS): A dissimilar metal joint between the ferritic steel (2.25Cr-1Mo) of the steam generator and the austenitic stainless steel (SS 316) of the sodium coolant system is used in FBRs. Ferritic steel pipe face is buttered with Inconel-82 filler metal. The stainless steel pipe and buttered ferritic steel pipe are welded using conventional manual TIG welding process with Inconel-82 filler metal. A similar joint is also made without a buttering layer. A joint with buttering layer was found to reduce residual stress in ferritic steel fusion zone (Joseph, 2005).

Multilayered Bimetal Laminate Composites: Laminated metal composites (LMCs) consist of bonded alternating thin layers of dissimilar metals. Elemental metal foils are stacked together and rolled to cause enough strength/weight ratio, high impact and fracture resistance (Chaudhari, 2009). The interface (intermetallic compounds) resulting out of diffusion of dissimilar metals is responsible for crack arresting/deflecting capability. However, the ductility of these metallic systems is a cause for concern and need to be improved by other means (Goda, 2002). LMCs are finding applications in the aerospace, automotive, and electronics industries. The family of LMC systems include Ti-Al, reinforcement of Al alloy with stainless steel/maraging steel and reinforcement of Ti alloys with high strength steel, Ti-$TiAl_3$, ultrahigh carbon steel(UHCS)-mild steel (Carreno, 2003).

2. CONCLUSION

It is evident that bimetallic components provide scope for customizing material properties to withstand conflicting service conditions. The challenge is to join dissimilar metals with good bond strength and free from interface defects. With the development of advanced joining techniques, the concept of bimetals can be explored in large scale.

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