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Joint-site structure friction welding method as a tool for drive pinion light weighting in heavy-duty trucks

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ABSTRACT

To satisfy the applied compressive stresses of friction welded drive pinion fabricated by using the joint-site structure (JSS) method, three different variants were followed: (A) the initial design with two joints was carried out. Two different burn-off lengths were examined for this variant. (B) The optimum burn-off length was considered for only one weld zone. (C) The weld zone was moved radially from the initial location and two different gap sizes were compared. The smallest gap size for the third variant led to the largest weld length. The lack of structural welding defects for this variant was assessed by ultrasonic testing. Hardness of the material after friction welding (FW) was correlated to the Continuous Cooling Transformation (CCT) diagram of the used materials and revealed the phase/microstructure transformation of the material. The simulated applied stresses on the optimized friction welded design of the drive pinion showed suitable results. The new drive pinion friction welded by the JSS method reduced the weight of the component by approx. 14%.

1. Introduction

Fuel efficiency is a key profit factor for the long-haul transportation industry. In heavy-duty trucks, lightweight design is very important for achieving further fuel consumption reduction and increasing the truck payload. Klein (2011) and Grubisic (1986) stated particular requirements of lightweight designs emphasizing the material properties, geometry and the ability of the materials to withstand high stress. In order to achieve fuel efficiency, one of many lightweight design approaches is to focus on weight-reduction for truck components such as the drive pinion, i.e. the component that is the main focus of this research. The current industry-standard drive pinion is produced as a solid forged single-piece part. Quintenz and Raedt (2009) and Neugebauer et al. (2001) made use of a hollow shaft to significantly reduce the weight of components. In order to achieve suitable weight reduction and avoid relatively expensive conventional methods (such as drilling the shafts), a hollow shaft was used in this research. The hollow shaft was joined to the bevel using a FW technique.

Designing bimetallic parts using expensive materials only when they are essential creates significant cost-saving opportunities. Dissimilar materials applied for the bevel gear and the shaft parts, for instance, substitute the current homogenous material of the drive pinion. Bevel gears are usually highly stressed, so that high-quality demands on the material are fulfilled. In contrast, the shaft material can be chosen to be less expensive. According to the American Welding Society (AWS (1989)), FW is the ideal method for joining metals that are not necessarily similar. Donohue (2008) mentioned the cost advantages of using composite rather than one piece shaft in FW of the pump. Machedon and Machedon (2007) demonstrated the application of FW for some automobile components in which FW of the drive shafts replaced electric arc welding technology. Using this method, the end component fitting process was simplified and the costs were reduced too. Grünauer (1987) discussed possible weld-zone geometries for different components. In a patent registered by Fett and Colbert (2000), the axle portion was friction welded to the flange portion of the motor vehicle axle shaft. Kong et al. (2010) tested the replacement of the as-forged automobile reverse idle gear shaft with friction-welded dissimilar joints. They found the optimal FW parameters for this test.

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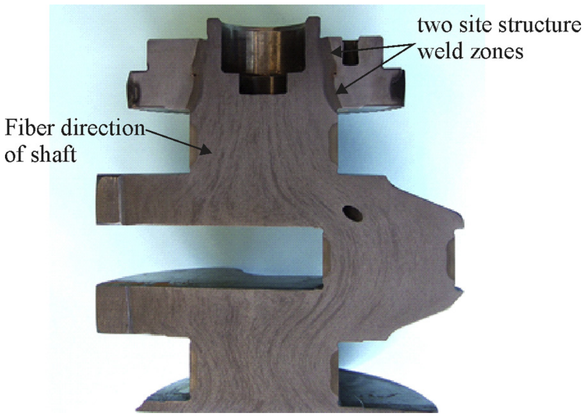

Fig. 1. JSS of friction welded crankshaft.

FW was introduced as a joining method for circular profiles, used in most cases for butt welding. However, Nied et al. (1995) invented a method for FW a shaft to a disk having the tapered wedge on both parts, resulting in a weld interface in an area of lower stress compared to conventional butt welding. Steinmetz et al. (2011) introduced a new JSS FW method, in which a shaft was joined to the gear of a crankshaft. They discussed the advantages of this method of shaft/crankshaft joining for preventing the interruption of the fiber direction of the shaft and the consequences for the strength of its gear teeth part. Fig. 1 shows the JSS of the crankshaft and its advantage. Bernhard et al. (2007) registered a patent applying site structure for joining a shaft to a disk hub connection flange by FW. The shaft and the hub are joined by overlap FW in which, in contrast to the end-face conventional FW, the surfaces to be joined are arranged at the circumference of the component. Two defined gaps prevent spread of the softening material during FW. The benefit of this method has been clearly recognized and experimentation is underway to apply this method for other components, such as drive pinion.

Four different geometries for FW of a bevel to a hollow shaft and reducing the component weight were tested and compared by Mohammadzadeh Polami et al. (2012). In this investigation, the similar JSS shown in Fig. 1 was adapted for the truck drive pinion. However, it was demonstrated that this joint cannot withstand the applied stresses on the drive pinion gear part. Therefore, this method needed to be optimized.

Sahin (2005) discussed the most important parameters affecting the FW process, such as friction time, friction pressure, forging time, forging pressure and rotation speed. Sathiya et al. (2005) demonstrated that the burn-off length, defined as the difference in specimen length before and after friction welding, tends to increase with increasing friction time. Sathiya et al. (2007) discussed the optimum friction time and forging pressure at which higher strength of ferritic stainless steel joints was obtained. They also concluded that the burn-off rate played an important role as regards the metallographic structure and mechanical properties of this joint. Bennett et al. (2011) described that the time to the transition to gross plastic flow at inertia FW shortens as the friction pressure increases. This is due to the higher friction pressure causing an increase in heating rate around the interface region, which initiates plastic flow at lower temperature. In any case, the material needs to become pasty enough during the process. According to DIN EN ISO 15620, a sufficient burn-off period is required for generation of heat to permit consolidation during forging. The friction machine is usually adjusted to a specific burn-off length, until which the friction continues. Nevertheless, information regarding the JSS FW is limited only for few experiments indicating this explanation is insufficient. Therefore, in this study it is tried to find the appropriate friction pressure and time, for the material to become pasty enough and get the required upset length.

This investigation aims to design the JSS for a bevel/shaft composite workpiece in order to reduce the drive pinion weight, minimize defects and maintain a compliant fatigue strength. From the FEM simulation results demonstrating the stress requirements for the drive pinion, the optimal number of joints and locations, were obtained. For optimal joints, two different gap sizes were analyzed and compared. Micrograph analyses in conjunction with non-destructive ultrasonic testing proved good weld quality of the optimized design. HV10 hardness measured in the middle of the weld zone and its influence on the CCT diagrams of the joined materials showed the thermal capacity during the test for the last two variants.

2. Materials and methods

2.1. Materials

The bevel part was produced from a higher strength material, i.e. 18CrNiMo7-6, since, the gear teeth, machined later on this

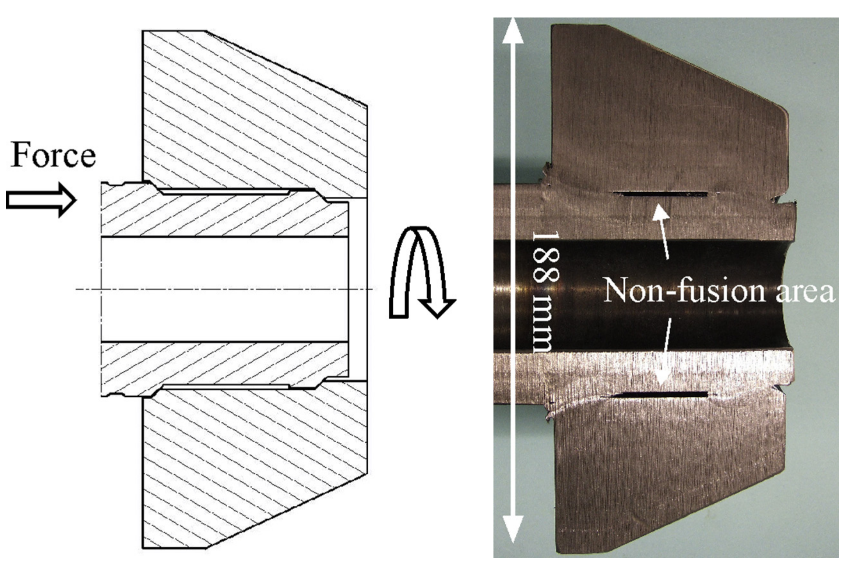

Fig. 2. Initial design of JSS FW for drive pinion (left side before FW, right side after FW).