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Designing energy dissipation properties via thermal spray coatings☆

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ABSTRACT

The coefficient of restitution is a measure of energy dissipation in a system across impact events. Often, the dissipative qualities of a pair of impacting components are neglected during the design phase. This research looks at the effect of applying a thin layer of metallic coating, using thermal spray technologies, to significantly alter the dissipative properties of a system. The dissipative properties are studied across multiple impacts in order to assess the effects of work hardening, the change in microstructure, and the change in surface topography. The results of the experiments indicate that any work hardening-like effects are likely attributable to the crushing of asperities, and the permanent changes in the dissipative properties of the system, as measured by the coefficient of restitution, are attributable to the microstructure formed by the thermal spray coating. Further, the microstructure appears to be robust across impact events of moderate energy levels, exhibiting negligible changes across multiple impact events.

1. Introduction

Energy dissipation within a system during an impact event is a velocity and material dependent property that is often associated with the plastic and viscous response of a material [5,15,33,41]. Traditionally, in order to augment the dissipative properties of a system without changing the materials, the structural design of a system (the locations of mass centers, magnitude of inertias, radii of curvatures, etc.) must be changed [4]. An alternative approach is to change the microstructure of the contact interface [26]; however, this can become expensive and challenging due to the necessary manufacturing processes for creating a robust microstructure that will persist across macro-scale impact events.

Thermal spray coatings [11,12,39] present a unique opportunity to change the microstructure of a surface without incurring a significant development cost. The category of thermal spray coatings encompasses several related manufacturing techniques. The commonality amongst these techniques is that particles of the size of approximately 100 nm to 1 µm are heated and sprayed onto a substrate. Depending on the specific thermal spray methodology, particle temperatures in excess of 4000 K and particle velocities up to 1000 m/s are achieved. Details of the manufacturing process of thermal spray coatings can be found in the review of [30]. Presently, thermal spray coatings are used extensively to improve the wear and tribological properties of a system [31]; however, they are known to have advantageous dissipative properties due to internal friction acting along the splat boundaries [18,19,20,29,36,43,44,51]

The microstructure of the coatings deposited via thermal spray methodologies is referred to as a 'splat' network. Similar to grain networks [34,47], splat networks consist of a matrix of 'splats', each formed from the high velocity impact of a droplet of heated metal deposited on the surface via a thermal spray process. As illustrated in Fig. 1, splat networks can consist of voids, unmelted particles, and large, flattened splats. Similar to grain networks, the microstructure of splat networks can significantly affect the bulk mechanical properties of a solid [1,24,25,37,38,45,46,50]. For thermal spray coatings, the microstructure is dependent upon the particle conditions at impact (e.g. temperature and velocity) as well as the material properties of the particle and substrate (such as substrate roughness [27] and moduli [28]). The particle conditions are determined by the process parameters of the thermal spray, including spray pressure and composition [17,49], particle velocity and size [8], and specific gas heating and acceleration source [46] amongst other parameters [9,17].

In what follows, thermal spray coatings are investigated for engineering the dissipative behavior of a system. The thermal spray

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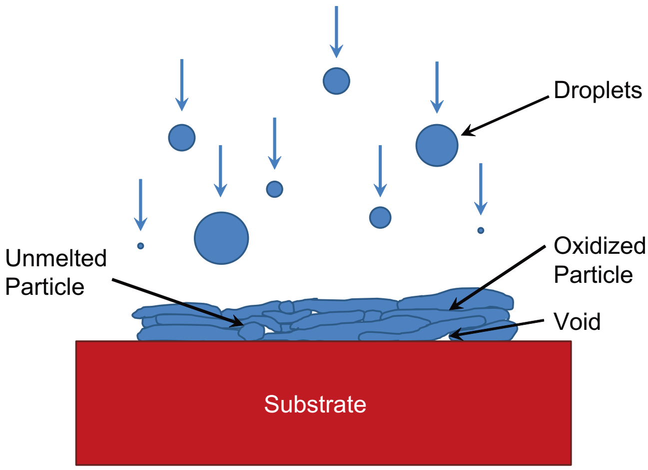

Fig. 1. Illustration of the formation of a splat network from thermal spray coating methodologies.

process is detailed in Section 2, and the dissipation measurements are reported in Section 3. To assess potential dissipative mechanisms, the microstructures of the impacted specimens are analyzed in Section 4. Finally, Section 5 summarizes and presents conclusions from this work.

2. Sample preparation

Samples are fabricated using 304 stainless steel pucks that are designated into one of four conditions: control (no coating), dense coating, porous coating, and middle coating. The variations in the coating properties here are determined primarily by the thermal spray velocity, particle temperature, and flow density. The dense and porous coating conditions are intended to represent the extreme conditions that could be easily fabricated while the middle coating is an average value for the thermal spray application properties. In all cases, the coating applied to the coupons is the same: 304 stainless steel. No polishing or other conditioning is performed after the coating process[1]. The control sample, by contrast, is polished to remove all asperities larger than 100 nm. The literature on the effect of surface roughness on coefficients of restitution at a scale in which adhesive forces are negligible is somewhat limited (otherwise, see [35]). The strongest conclusion observed is that surfaces with higher roughnesses exhibit a higher standard deviation in the measured responses for impacts of a sphere against a flat [40].

The stainless steel coatings are fabricated using a twin wire arc spray process, which is a droplet deposition coating process. A twin wire arc spray coating is applied using an arc spray torch, which brings two electrically energized feed stock wires together. When the wires cross, an arc (similar to a welding arc) forms between the wire tips, melting them. A gas stream injected behind the arc atomizes the molten feed stock material and propels it downstream. When molten droplets of the feed stock material encounter the substrate they flatten, solidify, and form a coating with the characteristic lamellar structure associated with droplet deposition.

All coatings were prepared using a Praxair/TAFA 9935 twin wire arc torch controlled using a 9910 CoArc console. The torch was outfitted with a blue nozzle and short cross nozzle positioner for all spraying. A 1.58 mm diameter 88T 300 series stainless steel wire feed stock (Praxair/TAFA) was sprayed onto 2.54 cm diameter by 3.81 cm long stainless steel substrates using dry, oil free air. The torch was mounted on an ABB-IRB 6600 six axis robot used to control standoff distance and move the torch over the substrates in a raster pattern. The raster pattern was accomplished using a 200 mm/s traverse speed, a 10 mm step size, and a 400 mm/s step speed.

Table 1
Torch operating condition ranges.

	Hot and fast	Middle	Slow and cool
Standoff distance	15 cm	30.48 cm	45.75 cm
Atomizing air pressure	330 kPa	234 kPa	137 kPa
Arc current setting	150 A	150 A	150 A
Arc voltage setting	21 V	21 V	21 V

The substrates were grit blasted, degreased, and cleaned before spraying. Table 1 shows the range of operating parameters used for these experiments. The 9935 torch has two primary process settings, atomizing gas flow and arc current. Wire feed rate is controlled automatically based on arc current settings such that a constant voltage and arc length is maintained across the wire tips. These parameters were chosen to produce a range of droplet velocities and droplet temperatures so as to produce a range of coating densities. In general, slower and cooler droplets are expected to produce more porous coatings than hotter and faster droplets [10,13,14,32,48,49].

Samples were roughened using a Guyson manual grit blaster spraying Metcolite F Al_2O_3 grit (Sulzer-Metco) at 550 kPa pressure to achieve a surface roughness of approximately 14 µm Ra. After grit blasting, samples were rinsed with acetone and isopropyl alcohol, and dried using compressed air. Samples were thermal spray coated as soon as possible after grit blasting, with the time between grit blasting and coating never exceeding two hours. A coated sample is shown in Fig. 2.

3. Coefficient of restitution experiments

The coefficient of restitution is defined as a measure of the energy retained during an impact event (i.e. a coefficient of restitution of 1 corresponds to no energy loss, and a value of 0 corresponds to 100% energy loss). To measure the coefficient of restitution, a large-scale impact experiment (detailed in Section 3.1) is utilized in which a long pendulum is used to impact the test specimen at relatively low impact velocities. The large scale setup is chosen instead of a system such as a micro- or nano-indenter due to a motivation to understand the dissipative properties of the coatings in a context similar to the motivating application for this research.

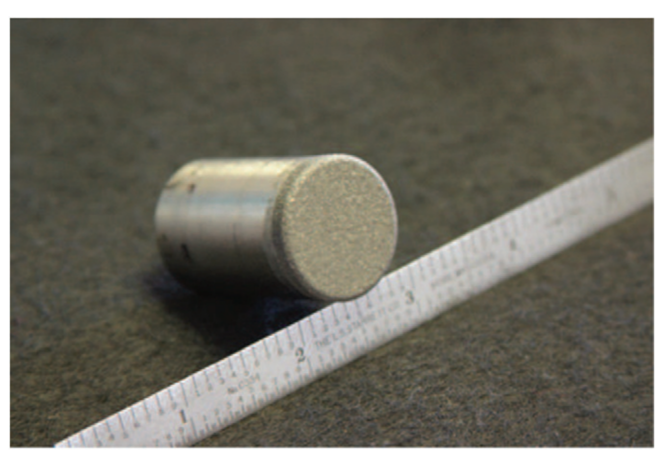

Fig. 2. An arc spray coated sample.

[1] Future work would be well served to polish all specimen to the same roughness level. However, this is outside the scope of the present research.