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EFFECT OF DENT GEOMETRY ON BOILING HEAT TRANSFER OVER SHOT PEENED SURFACES

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ABSTRACT

Boiling heat transfer depends considerably on the quality of surface over which boiling takes place. Shot peening can improve surface mechanical properties and at the same time it has been observed that it can improve the rate of boiling heat transfer. Details of relevant geometrical parameters of two types of basic surface dents viz. due to a spherical ball and due to a tetrahedron were studied and it was found that a tetrahedron dent has a larger ratio of dent surface area to projected area. This may provide more nucleating sites for boiling heat transfer.

1. INTRODUCTION

It has been known since long that boiling heat transfer is considerably affected by surface conditions of the heating interface, roughness, wettability of surface and surface tension of the liquid. In the engineering situation like steam generators in thermal power plant once the working fluid is decided there is not much of a control over the properties of boiling liquid such as surface tension, saturation pressure, temperature etc. However surface properties like roughness and wettability can be controlled for improved boiling heat transfer. Jacob (1936) studied the boiling heat transfer on three surfaces (a) a surface covered with a layer of thin oil, (b) a partially wettable polished chromium surface and, (c) a specially prepared `screen' surface with cubicle cavities of linear dimension and spacing of about 0.25 mm, which became fully wetted. It was noticed that roughness of specially prepared cubicle `screen' surface counteracted the surface tension, and the plate became completely wet and gave increased rate of heat transfer. Higher wettability due to surface roughness resulted in large number of nucleating sites, which gave off increased number of bubbles and thereby increasing the boiling heat transfer many fold compared to heat transfer by natural convection and boiling on untreated surface. The phenomenon has since heen described in related technical literature (Geidt, 1957; Gebhart, 1971; Sharma et al., 1989) on the topic.

2. HEAT TRANSFER ON SHOT PEENED SURFACES

Creating the surface roughness by various means increases the turbulence level in boundary layer thereby increasing convective and boiling heat transfer. But such an action on surface could adversely affect the mechanical properties of the heating surface. This is undesirable specially if the wall thickness is small. Shot peening improves the mechanical properties of the surface at the same time provides the surface roughness which increases the wettability and provides numerous nucleating sites. Using this idea Sharma and Mubeen (1986) and Nadkarni, et al (1990), applied shot peening to study boiling heat transfer and found that heat transfer rate improved considerably by shot peening. Nadkarni et. al reported improvement in boiling heat transfer rate in the range of 13% to 140% by shot peening, grit peening and by using M seal compound coating on boiler quality steel tube. An important observation was that grit peened surface provided considerably higher heat transfer rate than that of shot ;peened surface. As an abundant caution it is worth repeating that in the process of shot peening compressive indentation is required on the surface rather than scratching as is the case in blasting machines which are mostly used for descaling, surface cleaning, deburring etc. Nahar (1991), Tiwari (1991) have clearly mentioned that shot peening with brokedn spherical shots will result in grit peening and will be injurious to the fatigue life of the component and therefore defeating the real prupose of improving the surface mechanical properties. Sharma's (1996) results, however indicate no major damage to surface due to controlled grit peening as was indicated by Nahar (1991) and Tiwari (1991).

3. GEOMETRY OF INDENTATION

The higher rate of boiling heat transfer in case of grit peened surface as compared to shot (ball) peened surface makes it befitting to look into the details of geometry of indentation and possible mechanism. Qualitatively, the indentation of the ball will be comparatively flat than the indentation of a grit particle which most likely will have sharper points and / or edges. However the impact on the surface by the particle will result in an indentation, the geometry of which will decide whether the surface mechanical properties are improved or adversely affected. Further from the point of view of heat transfer shot peening / grit peening will provide (a) roughened surface which will affect the convection flow, (b) more nucleating sites for vapour bubbles, in form of peaks and valleys. At this point it is of interest to note that Mikheyev 1977 determined the minimum radius of starting point at a given temperature difference in a boiling liquid at which generation of vapour bubble is possible. The growth of still smaller bubble is not possible or else the pressure inside the bubble exceed that of equilbrium. In a sample case of boiling of water at atmospheric pressure with temperature difference varying from 5 ^{0}C to 25 ^{0}C, the minmum radius of acting starting points changes from 6.7 micron at 5 ^{0}C to 1.29 micron at 25 ^{0}C.

It will be desirable but difficult to analyse different types of indentations of particles of numerous geometries and orientations, and their distribution over the surface. It is felt, that two extreme cases of geometry of indenting particle can be looked into. The first, a sphere volume for unit surface area, and the other a tetrahedran where the material is enclosed by minimum number (four) of planes, and which has minimum volume for unit surface area. In case of tetrahedran the normal to its base is along the depth of indentation, vertex hitting first. The characteristic length L, for the particles is taken as ratio of its volume to surface. Thus for a sphere of radius `a' its characteristic length is 0.3333a. and for a tetrahedron of side `a' its characteristics length is 0.068041a. Heat transfer to liquid in the dent from the surrounding hot surface will be enhanced *if the dent has significantly higher surface area than the projected area on the* surface of the component. This increases the nucleating sites.

Information regarding the variation of (a) dent surface area Ad (b) projected area of lthe dent on the surface Ap (c) ratio of dent surface area to projected area Ad/Ap; with the depth of the dent "d" is tabulated. The depth of the dent is made non-dimensional by dividing it by characteristic length of the sphere or tetrahedron (L = volume/surface area). Further dent surface area and projected area are made non-dimensional by dividing it by square of characteristic length (L^2).

d= depth of dent   Ad = Surface area of dent

L = Characteristic length of particles   Ap = Projected area

Sl. No.	d/L	Sphere			Tetrahedron		
		$Ad/L^2 x10^2$	$Ap/L^2 x10^2$	Ad/Ap	$Ad/L^2 x10^6$	$Ap/L^2 x10^6$	Ad/Ap
1.	0.001	1.884	1.884	1.000166	1.9486	0.64952	3
2.	0.002	3.769	3.768	1.000334	7.7942	2.5981	3
3.	0.005	9.424	9.416	1.000834	48.914	16.238	3
4.	0.010	18.849	18.818	1.001669	194.86	64.952	3
5.	0.020	37.698	37.573	1.003352	779.42	259.81	3
6.	0.050	94.247	93.458	1.008442	4871.3	1623.8	3
7.	0.100	188.490	185.352	1.016950	19486	6495.2	3
8.	0.200	376.980	364.420	1.034490	77942	25981.0	3

4. DISCUSSION

The table shows the variation of dent surface area, projected area and ratio of the two, for d/L in range of 0.001 to 0.2 (since in shot peening depth of dent is extremely small), for two geometrical configurations of the dent on the surface. For smaller depth of the dent, the dent surface area for ball (sphere) is greater than that due to tetrahedron. This is basically due to the fact that in peening, ball is flat at the point of contact whereas tetrahedron is just a point at the contact. Further the dent surface area increase proportionally with the ratio d/L in case of sphere, whereas dent surface area, in case of tetrahedron increases in proportion to square of the ratio d/L. The variation of projected areas with the ratio d/L, in both the cases have the trend as that of dent surface areas. An important result is that the ratio of Ad/Ap in case of sphere is very close to unity, and incase of tetrahedron it is three. This indicates that the roughness so obtained by spherical shot peening is less than that would be obtained by having tetrahedron shot (dents). Besides, higher this ratio, rougher will be the surface and therefore more nucleating sites are expected on surface dented by tetrahedrons. Nadkarni et. al (1990) reported such a case in their experiments. This brings in the question of udesirable mechanical properties (fatigue and fracture) due to shot peening by sharp object like tetrahedrons. But scratch or sharp cut on surface is different than sharp compressie dent. It is hoped that by controlled experiments, shot peening parameters can be obtained which will give higher boiling heat transfer on the surface and reasonable improvement in surface mechanical properties due to tetrahedron-grit peening of the surface.

5. CONCLUSIONS

Geometrical parameters of two types of dents, one spherical and another tetrahedron were estimated. It is found that tetrahedron dents have greater Ad/Ap ratio and may provide more nucleating sites and thereby increase heat transfer rate in boiling.

Experiments with tetrahedron shaped/ grit/ sharp particle peening are needed to assess adverse surface properties since sharp cut and scratch are basically different from compressive impact prevailing in grit peening.

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