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Durability Evaluation Method of Handling Structure using Hand Calculation and Simulation

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수계산과 해석을 이용한 핸드링구 내구성 평가 방법 고찰

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ABSTRACT

Most product structural components are assembled by various members and castings except casting products. In such cases, a particular structure is required to move and fix each component. In particular, the safety uncertainty of heavy product assemblies can be linked to large accidents. Thus, the safety design and evaluation of additional structures have become more important. In the field and factories, these additional structures are called handling structures, which are designed and manufactured. As the types of products produced become more diverse, the design and manufacture of a handling structure are also diversified. The results of each evaluation should be derived. We develop a logical design and evaluation method, which was previously designed based on empirical data, for the handling structure.

Keywords : Handring Structure(핸드링구), Duarability Assessment of Welding(용접부 내구성 평가), Hand Calculation(수계산), Simulation(해석)

1. Introduction

The handring structure used for assembling and moving the structures are applied frequently in production at the factories and sites. The handring structure, which frequently gets in touch with the workers, has been rather treated in a simple manner and relied only on empirical data. However, the unintentional use of the handring structure can lead to breakdown, which can lead to industrial accidents such as a falling accident or spurious accident. Especially, in the so-called “Fourth industrial revolution” era, new products have increased, and an old fashioned empirical design can be a big problem. Therefore, this study was carried out in order to present logical and quantitative design method of handring structure from previous empirical design. The design and durability evaluation results presented in this study will be a clear measure of safety management with the use of safe handring product.

Existing handring structure designs are based on

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empirical design without any quantitative calculation. This is because, if the production of conventional products continues, it is possible to design low risk based on many trial and error, but it possesses a danger of a great safety accident when a new product is produced. Also, considering the durability evaluation method of the existing handring structure, the evaluation method of the welded part and the base material part are identical, so that the uniqueness of the welding is not considered. It is estimated that this is based on empirical qualitative safety classification rather than evaluating the durability of the handring structure based on clear criteria. The design method and the evaluation method have been obstacles to effective safety management of handring structure.

In this study, AWS and IIW, which are design evaluation criteria of welding products, were used for the design method and durability of hand structure. In addition, simulation was used to evaluate the durability of the overall shape. The evaluation method of the welded part and the base material part is different in the analysis method setting, so that the fracture aspect and characteristics possessed by the welded part and the base part can be considered. And, since the simulation is an evaluation method that generates a large difference in value depending on the competence of the performer, an Excel evaluation sheet using an engineering formula is developed to ensure the reliability of the simulation results. The evaluation method and the verification method are applied to the field of the design and evaluation of the handring structure of the durability evaluation using the simulation and hand calculation. And, it will be a logical basis. In addition, the simulation manual prepared in this study will be helpful for the workers who are new to the design of handring structure.

The diversified products and shortened product life span in the 4th industrial revolution will urge the production of more diverse products in the future. Therefore, the shapes and types of handring structure used in assembling and moving product members will be further diversified. This situation will not have the time to establish an empirical design and verification procedure based on existing trial and error. Therefore, it is expected that the handing structure evaluation method presented in this study will provide logical criteria for the field and the factory where the time margin is insufficient and safety management becomes more important.

2. Preliminary Backgrounds for Design of Handring Structure and Durability Evaluation

2.1 Welded Part Design

If you look at the Fastener as a method of assembling a member, it can be divided into Clamped joint, Pinned joint and Bonded joint. Clamped joints are divided into Bolted joints and Sprung joints, and Bonded joints are divided into Welded joints and Glued joints (Fig. 1). Each of the joining methods has advantages and disadvantages. However, welding can be considered as a method of transferring a strong force to the assembly part, economically making the shape desired by the designer of the raw material of flat or curved surface, and obtaining the strength of the robust assembly part. Welding is defined as a metallurgical process that narrows the surface of two metals to within the interatomic bond distance[1]. For this purpose, welding is mainly in the direction of load transfer, and the material grains are

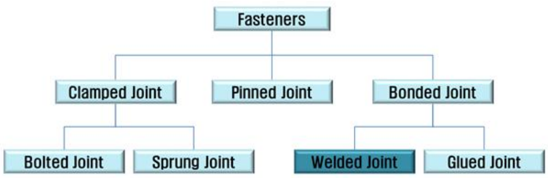


Fig. 1 Type of fasteners

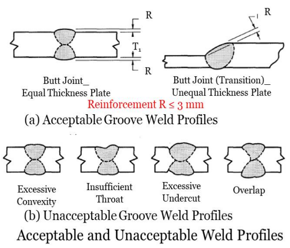
Table 1 Type of defects[2]

Type of defects	Commentary
Undercut	A portion that is not filled with weld metal at the edge of the weld portion and acts as a geometrical defect
Overlap	The part where the base material and the fusion-bonded metal elements are melted and not joined to each other at the edge of the welded part
Fish eye	Appearance of silver-white eyes on the wave surface due to intervening material defects present in the weld metal
Slag inclusion	Defects in slag mixed with fused metal
Blow hole	Small worm-like pores present in the deposited metal
Porosity	The spherical porosity existing inside the deposited metal
Tungsten inclusion	A part of tungsten electrode melted in GTA weld and mixed into weld metal.
Burn through, Dripping	The phenomenon that the weld metal melts and falls under the weld
lack of penetration	Welding does not occur across the entire thickness and only partially occurs
Pit	Small hole on the bead surface
Lack of fusion	Phenomenon in which the interface between weld layers is not sufficiently fused
Crack	There are several examples of the following phenomena that occur in welds due to various causes.
Longitudinal crack	Cracks that occur in the direction parallel to the bead direction in the weld metal, heat affected zone (HAZ)
Transverse crack	Cracks that occur in the direction perpendicular to the bead direction in the deposited metal, HAZ
Sulphur crack	Cracks caused by segregated sulfur or sulfide
Bead crack	Cracks in beads
Underbead crack	Cracks beneath the bead
Toe crack	Cracks at weld edges
Hot crack	Cracks generated at high temperature beyond recrystallization immediately after welding
Cold crack	Cracks from welding near room temperature
Reheat crack	Cracks that occur when reheating welds or using them at high temperatures for a long time

transformation temperature of the material during the bonding process. Thus, the weld is considered to be a discontinuous point in the structure.

In this situation, along with the overall quality of the structure, the welding product should be aware of the local dimensional defects, structural defects and defects in the characteristic of the welds. Accordingly, the welds are subjected to nondestructive tests such as visual inspection, RT, and UT. The criteria of this NDT shall be more than the specifications specified by the standard. The defects occurring in the welds are shown in Table 1[2]. In this study, we focused on dimensional defects like undercut. This is because defects in structure and defects in characteristics are unpredictable in the design stage of welds.

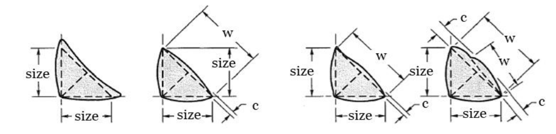
There are many specifications for welding design, but most of the specifications are based on AWS as a mother standard. In case of AWS, guidelines for designing the shape of the welded part are presented through classification of the connection shape of the base material. In addition, the manual is presented during the welding work by sorting by welding. The items shown and specified in Fig. 2 and 3 may be the basis for overall groove weld and fillet weld design and quality inspection. In the case of grooved welds, the maximum angles of welds can be checked for different thicknesses of the base metal. In addition, the fillet welding also describes the guideline of welding thickness according to the base material and the case of defective shape. In addition, AWS provides a method for setting the allowable stress of welds. According to the AWS code, it can



Base Metal Thickness	Minimum Weld Size
3 ~ 5	2
5 ~ 6	3
6 ~ 12	5
12 ~ 20	6
20 ~ 38	8
38 ~ 57	10
57 ~ 150	12
150~	16

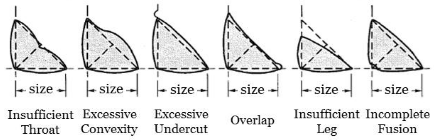
Partial Joint Penetration Minimum Weld Size (mm)

Fig. 2 Guidelines for groove welding[3]



(a) Desirable Fillet Weld Profiles (b) Acceptable Fillet Weld Profiles

W (mm)	Max c
~ 8	≤ 2
8 ~ 25	≤ 3
25 ~	≤ 5



(c) Unacceptable Fillet Weld Profiles

Acceptable and Unacceptable Weld Profiles

Base Metal Thickness	Minimum Weld Size
~ 6	3
6 ~ 12	5
12 ~ 20	6
20 ~	8

Fillet Minimum Weld Size (mm)

Fig. 3 Guidelines for fillet welding[4]

be confirmed that the permissible stress varies depending on the welding type and the load condition, and the welding part is weak to the shear[5]. The AWS welding guideline based on the nominal stress described above is a clear standard in the design of simple and basic welded parts in the design of handring structure.

2.2 Evaluation method of welding part

As mentioned earlier, welds represent discontinuities in the structure. Therefore, there have been many attempts to study accurate evaluation methods. Among them, IIW's research has achieved remarkable outcomes. The research results derived from the above-mentioned IIW point to the fact that the stresses in the welds are evaluated based on nominal stress, hot spot stress, and notch stress[6]. As shown in Fig. 4, it is assumed that the nominal stress is the same as the stressed member at the end of the weld. The hot spot stress is assumed to linearly increase the weld end stress, and the notch stress assumes that the weld end stress increases exponentially regardless of the surrounding substrate stress. According to the above assumption, in the case of the nominal stress, there are various stress lines to be evaluated according to the shape, and in the case of the hot spot stress, the stress line is smaller than the nominal stress but there is an evaluation stress line according to the shape. However, in the case of notch stress, there is only one evaluation stress diagram for any shape. Based on the evaluation stress line, the notch stress method using the R1MS method[7] with one evaluation stress line seems to be the simplest. However, as shown in Fig. 6, this method has difficulty in analytical modeling for beginners and difficulty in verification through hand calculation. Therefore, in this study, the analytical modeling is simple and the nominal stress is used which is easy to be verified by hand calculation. In addition, hotspot stress is relatively easy to calculate bye such modeling technique. However, it is difficult to verify the analytical results as well as notch stress, which is excluded from this study. The above-mentioned evaluation methods of the nominal stress, hot spot stress and notch stress assume that there is no welding defect such as weld defect and material defect mentioned in Section 3.1. The evaluated results were changed to finite life according to the S-N curve.

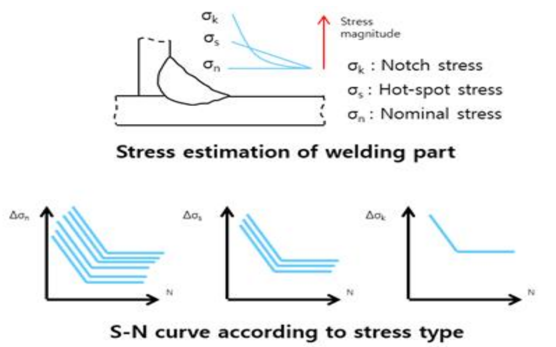


Fig. 4 Welding part evaluation method using simulation

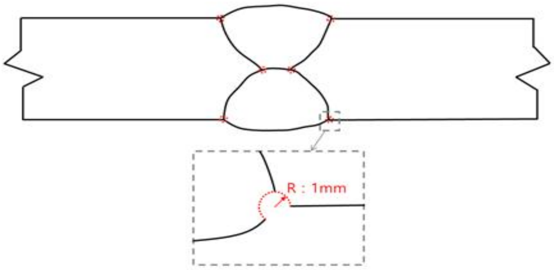


Fig. 5 Notch stress modeling method

2.3 Evaluation method of material part

In the case of welding product, the location where the breakage mainly occurs is the weld, but breakage may occur in the base material depending on the shape(Fig. 6., Equation 1). Unlike the welded part, the base material part has a low risk of defect inclusion and has a stable lattice structure, so it is evaluated as an infinite life time instead of a finite life time. In order to express this quantitatively to measure safety, it is expressed as numerical value of durability safety. The yield stress and tensile stress of the material used can be used as a basis for expressing the endurance safety. However, this method takes into account only uniaxial stress in the complex stress situation that the material can receive, so it may be difficult to derive accurate endurance safety. Therefore, this study used "haigh diagram" which is the most used method to express infinite lifetime numerically around the world. As shown in Fig. 6, the high diagram is a method of constructing a two-dimensional plane with two axes of mean stress and variable stress expressing the stress state of the product on the two-dimensional plane[8]. After that, we analyze the characteristics of the load acting on the product to express the durability safety rate (Fig. 7). Safety index for durability is determined by the application of the product. For example, in case of an elevator where breakage can lead to serious accidents such as human accidents, the safety factor can be set to a value exceeding 10. In this study, durability safety was set up considering the load, shape, the material deviation and engineering experience.

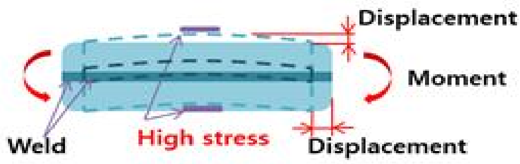


Fig. 6 High stress location by load and shape

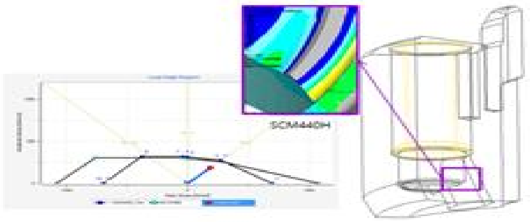


Fig. 7 Structural analysis results and haigh diagram use examples for durability safety[8]

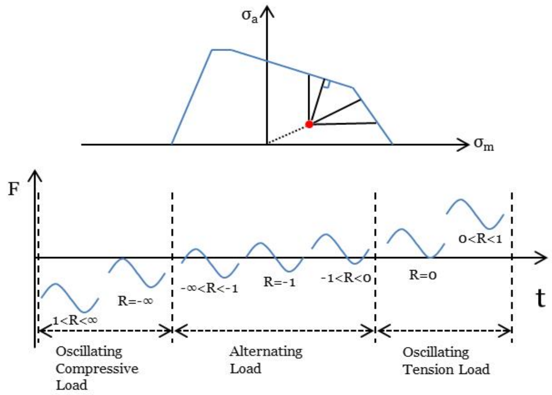


Fig. 8 Durability evaluation method according to load characteristics

$$\sigma_{M_x} = \frac{M_x}{I_{xx}} \times y_{\max} \tag{1}$$

3. Establishment of Durability Safety Evaluation Method for Handring Structure

3.1 Summary of Safety Evaluation Method Using Simulation

The new handring structure should be developed according to new product development method. However, the unintentional design and use of the handing structure can lead to safety accidents. Therefore, the endurance reliability of the handring structure design should be verified. Simulation, measurement, and test can be considered as a way to verify the durability of a product. However, in the case of test measurement, the manufacturing of the product must be completed and a relatively long time is required for verification. In the case of handring structure, development costs are low for developers and development schedules are much shorter than new product development cycles. Therefore, an endurance reliability evaluation method using simulation rather than measurement and test methods is appropriate.

Simulation is used for problems that cannot be simplified by hand calculation. Structure simulation is a method of finding approximate solutions by converting complex problems that cannot be solved by numerical calculation into linear equations (see Fig. 9). However, if the simulation direction and method are set, the reliability with respect to the value can be improved.

The main parameters of deriving the structure simulation results of the handring Structure are set as shape, load, and material(Fig. 10). In order to reduce the degree of freedom and improve the simulation efficiency in the case of the shape, the local shape of the non-hazardous part of the simulation result is simplified. In case of the load, the weight of the object is selected as the main load, and the impact load that can occur during the lifting is simulated. In order to clarify the flow of the load, the load application direction was selected based on the shape of the handring structure and the lifting member(Fig. 11).. In the case of materials, the related standards (KS[9], SAE[10]) for the SS400 material were identified and the evaluation results were analyzed(Table 2).

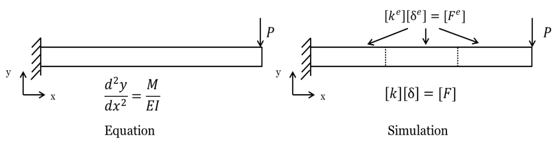


Fig. 9 Comparison of numerical calculation and simulation

The simulation method uses an inertial elimination method to prevent errors due to erroneous boundary

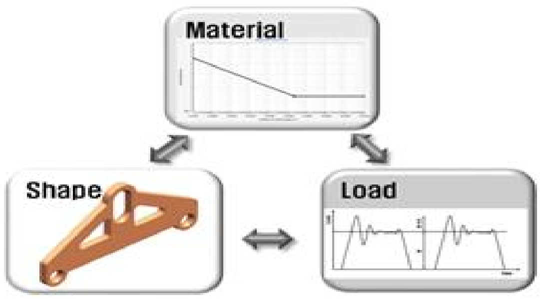


Fig. 10 Main factors of evaluation of durability of handling structure

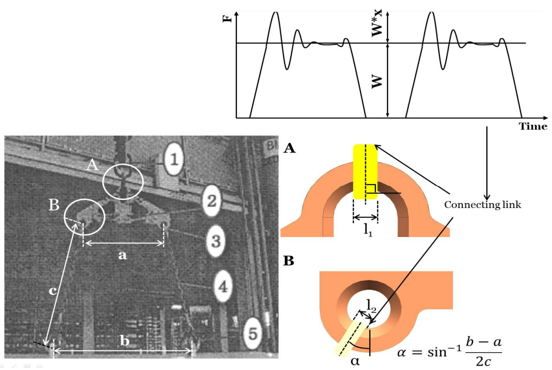


Fig. 11 Load condition setting for simulation

Table 2 SS400 evaluation criteria

	SS400
Yield strength	245 MPa
Tensile strength	400 MPa
Knee point	160 MPa

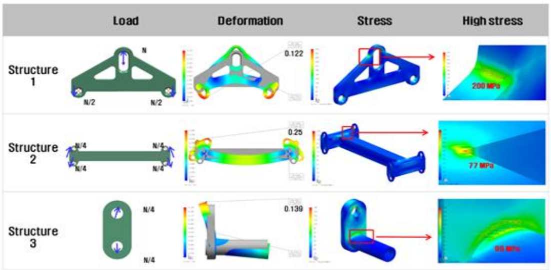


Fig. 12 Summary of simulation results of handring structures

conditions. The inertia removal method was considered to be suitable for the simulation of handring structure with a definite load{equation (3)}. The results of the simulation using inertia removal method are as follows. The simulation results were constructed so that the load application condition, strain shape, and high stress state can be clearly displayed(Fig. 12)

$$[K][u] = [P] - [M][a_0] \qquad (2)$$

Based on the simulation results, the von-Mises stress was used for the welds and the main stress was used for the base metal. In addition, the welded part is evaluated with finite life using S-N curve, and the base part is evaluated with infinite life using haigh diagram. Nominal stress was used to evaluate the welds. For conservative evaluation, the IIW FAT 80 diagram of the S-N curve of the nominal stress was used. The IIW FAT 80 curve maintains an exponent of 3 in the equation (3) up to 10 million cycles with a curve with an endurance limit of 80 MPa at 2 million cycles[11]. In addition, when evaluating the welding part using the graph of FAT80, the material of the base material portion does not matter. In the case of the base material part, the safety area of the haigh diagram is constituted based on the characteristic value of the material used, and the durability reliability is derived according to the load characteristic value R = 0. In order to improve

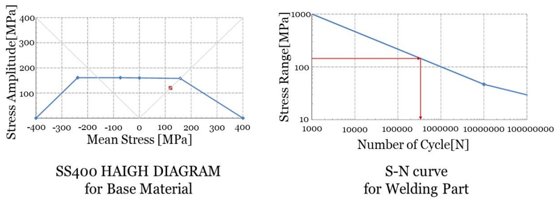


Fig. 13 Durability evaluation result of handring structure

the reliability of the evaluation results, the area of the haigh diagram was adjusted considering the survival rate, surface roughness[12] and etc.

$$N \cdot S^X = C \qquad (3)$$

3.2 Validation of Simulation Results

The basis of the simulation result analysis is stress. Therefore, the derived stress values should be verified. For this purpose, this study used the stress calculation method for tensile, compression, and bending, which are recognized globally. Then, the stress was used to calculate the equivalent stress of the von-Mises. Since the stresses derived from the simulation are nominal stresses, it is possible to make a comparison using the above results. The calculation results for welds are the same as those shown on the Excel sheet. In this study, a two-dimensional simplified method in AWS was used to calculate the weld stress.

Table 3 Stress calculation method according to each load

Working load	Shape characteristic value of welding part	Stress calculation formula
F_x	A_{yz}	$\sigma_{xx}=F_x/A_{yz}$
	A_{yx}	$\sigma_{yx}=F_x/A_{yx}$
F_y	A_{xz}	$\sigma_{yy}=F_y/A_{xz}$
	A_{xy}	$\sigma_{xy}=F_y/A_{xy}$
F_z	A_{xy}	$\sigma_{zz}=F_z/A_{xy}$
	A_{xz}	$\sigma_{xz}=F_z/A_{xz}$
M_x	I_{xx}	$\sigma_{Mx}=(M_x/I_{xx})*I_{max}$
M_y	I_{yy}	$\sigma_{My}=(M_y/I_{yy})*I_{max}$
M_z	I_{zz}	$\sigma_{Mz}=(M_z/I_{zz})*I_{max}$

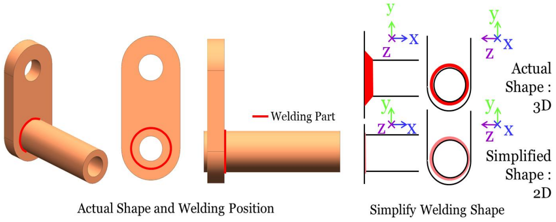
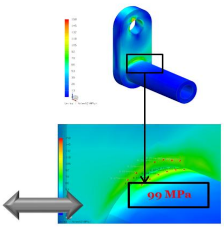


Fig. 14 Simplification of welds for calculation

Stress Component	Numerical Value(MPa)
σ_I	96
σ_{II}	0
σ_{III}	-4
Von-Mises	98



Hand Calculation Simulation

Fig. 15 Calculation of equivalent stresses in welding parts using excel

Comparing the stress value of 98 MPa derived from the above numerical calculation and the stress value 99 MPa derived from the simulation, it can be confirmed that the accuracy is very high. Through this, the reliability of the results using the simulation can be secured.

3.3 Summary of Durability Safety Assessment Procedures Using Simulation

The safety evaluation procedure for the durability of the handring structure using the above simulation was easily established for the operators unfamiliar with the structure simulation, and the safety evaluation procedure for the durability of the handring structure was established to improve the reliability of the results. The data of the evaluation procedure were organized in accordance with the simulation procedures : pre-process, solver and post-process procedure.

This process will help to dissolve the doubt on the simulation results by workers who are unfamiliar with simulation and their work.

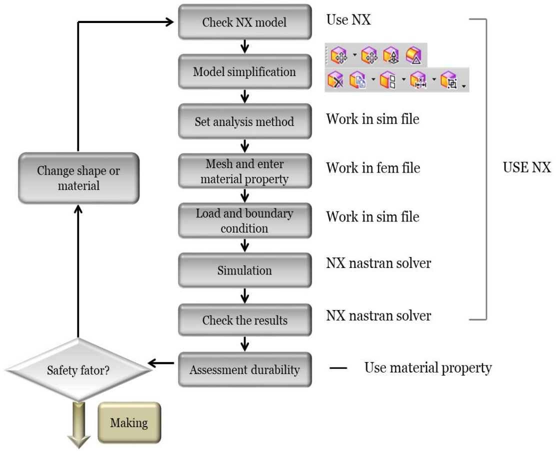


Fig. 16 Establish a handring structure process for durability assessment

4. Conclusion

This study was carried out in order to secure the durability, reliability of the handring structure which is essential for the product manufacture. In this study, we introduced a method using simulation to evaluate the stability of the endurance of a handring structure which requires a short development cycle and a clear safety value. The result of the simulation is a schematic for evaluating the safety by dividing the welding part and the base part. In particular, the welds, which are the main cause of breakage, are derived from the nominal stresses, and the reliability of the simulation results is secured by directly comparing the results that can be obtained later with the numerical calculation results. In addition, evaluation methods have been manualized to popularize the durability evaluation of the handring structure using the simulation and to reduce the dispersion of the simulation results. The evaluation of durability of the handring structure using the simulation derived from the above study will be helpful for the development site where the durability safety of the handring structure cannot be evaluated using the measurement and the experiment.

Acknowlegement

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